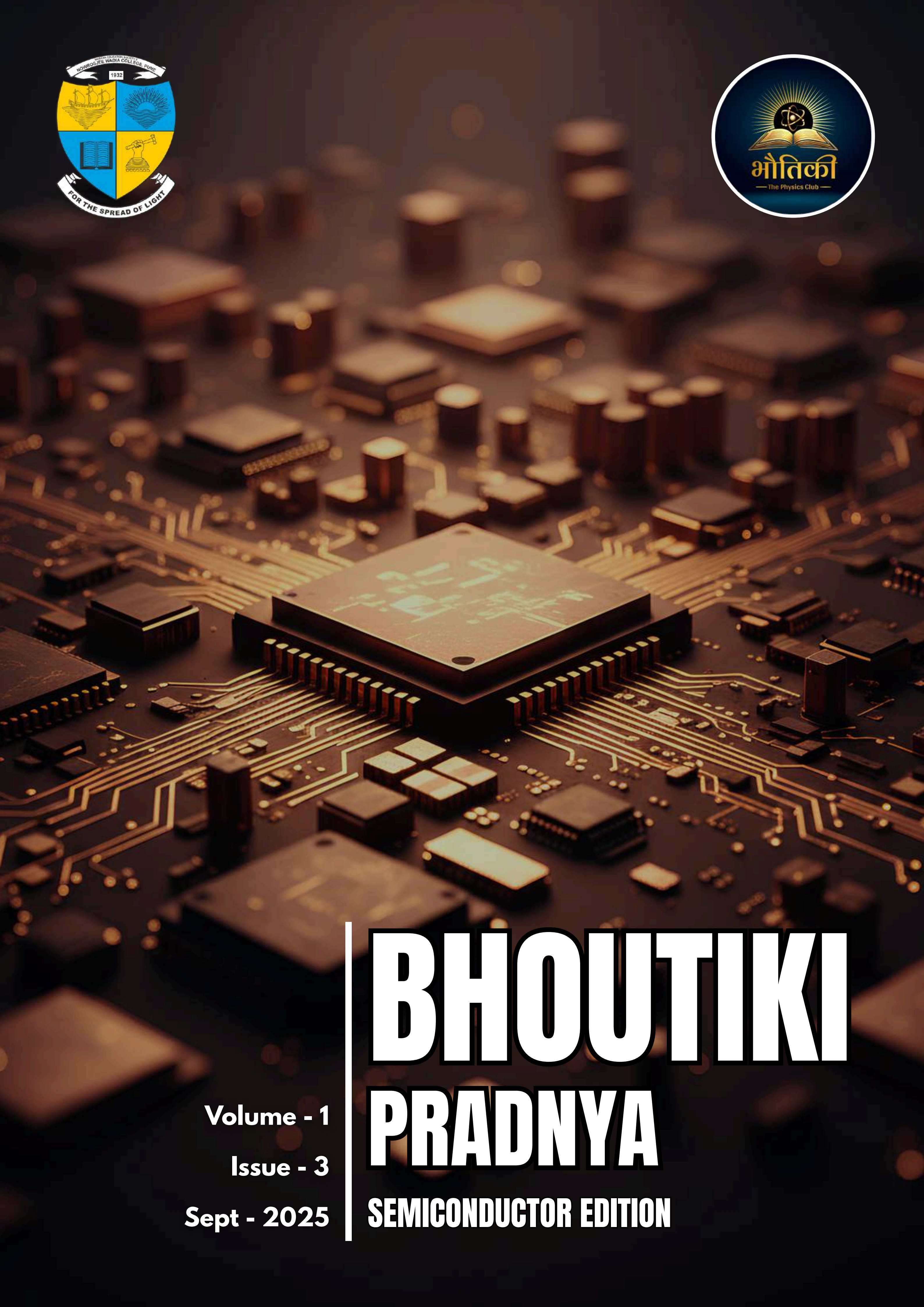
NOWROSJEE WADIA COLLEGE, PUNE
1932
FOR THE SPREAD OF LIGHT

भौतिकी
The Physics Club



BHOUTIKI PRADNYA

SEMICONDUCTOR EDITION

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PREFACE

In the ever-evolving landscape of modern science and technology, few innovations have shaped our world as profoundly as the semiconductor. From powering smartphones to enabling space exploration, semiconductors lie at the heart of the digital revolution. It is with great excitement and purpose that we present this special 'Semiconductor Edition' of BHOUTIKI, our e-newsletter dedicated to exploring the frontiers of physics.

Spearheaded by the enthusiastic minds of the BHOUTIKI Physics Students Club, this edition dives deep into the fascinating realm of semiconductors unraveling their physics, tracing their history, and spotlighting their transformative role in shaping the future. Whether you're a curious student, a passionate researcher, or simply someone intrigued by the invisible forces behind your everyday devices, this issue promises insights, inspiration, and innovation.

We extend our heartfelt gratitude to the MES's Nowrosjee Wadia College, for their unwavering support and mentorship. Their commitment to nurturing scientific curiosity continues to empower our journey from classroom concepts to real-world impact.

Let this edition be a celebration of electrons, energy bands, and the elegance of quantum mechanics woven together in silicon and sparked by imagination.

Happy reading,
Team BHOUTIKI Physics Students Club
MES's Nowrosjee Wadia College

In-Charge
Dr. Bharat B. Gabhale

ABOUT COLLEGE

Welcome to Nowrosjee Wadia College – A Beacon of Excellence Since 1932

Established on July 21, 1932, just months after the founding of the Modern Education Society, Nowrosjee Wadia College has stood as a pillar of academic brilliance and cultural vibrancy in Pune. Guided by its inspiring motto "For the Spread of Light," the college has been instrumental in opening doors to higher education for generations of students, especially in the eastern region of the city.

Affiliated with Savitribai Phule Pune University and proudly holding autonomous status, Nowrosjee Wadia College has earned numerous accolades, including the prestigious First Best College Award from SPPU and an A+ grade from NAAC in 2017. The college continues to shine as a consecutive Divisional Winner of JALLOSH, the university's celebrated cultural fest.

Offering a rich blend of undergraduate and postgraduate NEP 2.0) programs in both Science and Arts disciplines, the college attracts bright minds from across India and abroad. With world-class infrastructure, vibrant student life, and a legacy of excellence, Nowrosjee Wadia College remains the first choice for holistic education and personal growth.

ABOUT DEPARTMENT

Department of Physics – Advancing Research and Innovation

The Department of Physics at Nowrosjee Wadia College, Pune, is a recognized postgraduate teaching and research center under Savitribai Phule Pune University (SPPU). It currently offers comprehensive academic programs leading to B.Sc., M.Sc., and Ph.D. degrees, fostering a strong foundation in both theoretical and applied physics.

A hallmark of the department is the Electro-Acoustics Research Laboratory (EARL), an SPPU-recognized center for doctoral research. Building on its legacy of excellence, the department has expanded into Materials Science, with the Advanced Functional Materials Laboratory (AFML) offering cutting-edge research opportunities in nanomaterials and functional thin films. These studies focus on conductive and transient properties crucial to thin-film device technologies.

The department has successfully guided numerous Ph.D. and M.Phil. scholars and continues to mentor several active research candidates. Its commitment to innovation is supported by grants from prestigious bodies including the American Physical Society (APS), University Grants Commission (UGC), Indian Space Research Organization (ISRO), Department of Science and Technology (DST) and Board of College and University Development (BCUD-UoP).

ABOUT BHOUTIKI

The term 'BHOUTIKI' in the Physics Club logo likely signifies 'Physics' in Sanskrit, encapsulating the foundational principles of the natural sciences. It beautifully reflects the essence of exploring the physical universe, spanning phenomena from the microscopic to the cosmic scale.

Through 'BHOUTIKI,' we aim to honour the legacy of scientific excellence and inspire a new generation of physicists to delve into the mysteries of the universe.

Throughout the year, the club will host a wide variety of activities, each thoughtfully designed to spark curiosity and deepen participants' understanding of the intricate beauty of physics. These activities include: Guest Lectures and Seminars, Workshops and Skill Sessions, Experimental Demonstrations, Science Outreach Programs, Debates and Panel Discussions, Physics Quiz Competitions, Project Showcases, Movie Screenings and Discussions, Publication of Quarterly Digest, Experiment Design Competitions, Peer Teaching and Learning, Problem-Solving Sessions, Celebration of Physics Days, Collaborations and Competitions, Educational Visits, PHYSIQUEST: The department's flagship annual event.

With this diverse range of initiatives, the Physics Students Club aims to foster a vibrant community that celebrates the pursuit of knowledge and the joy of discovery in the realm of physics.

CONTENT

Foldable Gallium Nitride (GaN) based Electronics for Cryogenic Space Systems.

Ajay Borkar, PhD
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1. Introduction

The rapid evolution of space exploration and satellite technology has driven demand for advanced electronic systems that are lightweight, compact, and resilient to extreme environments. Next-generation astronomical observatories, cryogenic propulsion systems, and quantum payloads impose conditions that traditional silicon-based electronics cannot reliably withstand. At temperatures as low as 4–20 K, coupled with high radiation exposure and mechanical stresses, silicon devices fail due to carrier freeze-out and reliability degradation.

Gallium Nitride (GaN) semiconductors have emerged as a transformative solution. With their wide bandgap, high breakdown strength, and superior thermal properties, GaN devices can function in ultra-low temperatures where silicon and even Silicon Carbide (SiC) struggle. When integrated with foldable, flexible substrates, GaN based electronics offer new paradigms for satellite miniaturisation, deployable payloads, and adaptable system architectures. This synergy supports compact designs, flexible stowage, and resilient deployment in space.

This article explores analysis of foldable GaN modules focusing on:

- Cryogenic behavior of GaN devices
- Substrate engineering and material-level considerations
- Packaging, reliability, and deployment strategies
- Architectural design patterns and current challenges

2. Environmental Constraints in Cryogenic Space Systems

Space systems face multiple design constraints that impact the performance and reliability of foldable GaN electronics. The main challenges include extreme temperatures, radiation exposure, mechanical stresses, and thermal management limitations.

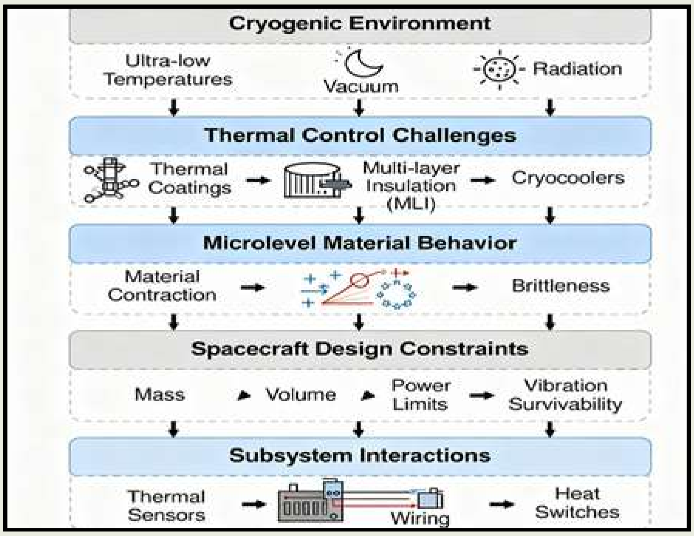

Figure 1: Cryogenic space environmental constraints.

The figure outlines the challenges and considerations in designing spacecraft systems for a cryogenic environment. It highlights how extreme cold and vacuum conditions affect material behavior, thermal control, and spacecraft subsystem design.

Temperature Extremes

Cryogenic payloads like infrared sensors, superconducting detectors and quantum communication systems operate at temperatures between 4-20 K, causing conductivity loss in conventional Si MOSFETs. Spacecraft exteriors experience temperature swings from 90-300 K due to solar exposure and shadow cooling, complicating system design.

Radiation Hardness

Deep-space missions face continuous bombardment from cosmic rays, protons, electrons, and heavy ions, causing damage to flexible substrates and polymers, necessitating radiation hardening engineering strategies.

Mechanical Constraints

Launches and in-orbit deployments require spacecraft to withstand vibration and shock loads, while foldable electronics must endure repeated folding cycles, vibration fatigue, and cryogenic contraction embrittlement.

Thermal Management

High thermal conductivity substrates like AlN are crucial for dissipating hot spots in GaN-based devices, while a mismatch in the coefficient of thermal expansion (CTE) can trigger microcracks during thermal cycling.

Material Interactions

Cryogenic cycling causes adhesives and polymers to contract, causing delamination. Radiation worsens these issues, compromising electrical and mechanical reliability. Therefore, material selection and hybrid layering are crucial.

3. GaN HEMTs at the Device Level

GaN High Electron Mobility Transistors (HEMTs) are the core devices in cryogenic GaN systems. Their unique structure allows continued operation where silicon-based devices fail.

- The AlGaN/GaN hetero-structures exhibit carrier freeze-out resistance, ensuring the stability of a 2DEG channel at a temperature of 20 K.
- Low temperatures decrease leakage but may lead to threshold drift, which can be fixed with SiN or Al_2O_3 passivation.
- GaN thin films maintain crystal quality under cryogenic cycling due to its microstructural integrity.

4. Substrate Engineering for Foldable GaN Modules

Substrate selection is critical for flexibility, thermal stability, dielectric properties, and radiation resistance at cryogenic temperatures.

Following figure provides a comprehensive visualization of the thermal management challenges and microstructural considerations for GaN devices operating at cryogenic temperatures (77K)

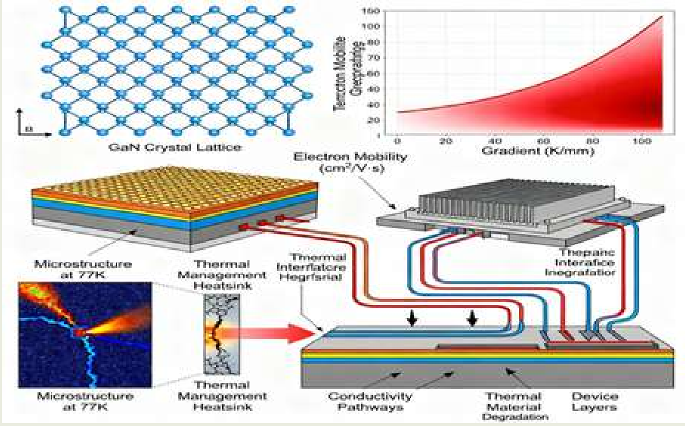

Figure 2: GaN HEMT cross-section

Carrier Freeze-Out Resistance

Unlike silicon MOSFETs, GaN/AlGaN hetero-structures sustain a two-dimensional electron gas (2DEG) even at 20 K. Polarisation effects maintain sheet charge densities above 10^{13} cm^{-2}, ensuring robust conductivity. This ability gives GaN devices a distinct advantage for cryogenic payloads.

Gate Control and Leakage

Low-temperature operation reduces thermally activated conduction, suppressing gate leakage. However, interface traps at the gate dielectric and GaN barrier may induce transient shifts. Advanced passivation with SiN or Al_2O_3 stabilises threshold voltage drifts to less than 50 mV across cryogenic cycles.

Micro-structural Robustness

Transmission electron microscopy studies show that transfer-printed GaN films on AlN or polymer substrates maintain crystal integrity post-cooling. Defect density remains low, supporting device stability under cryogenic stresses.

Substrate Engineering for Foldable GaN based Electronics

Substrate selection is a cornerstone of reliability and performance in foldable cryogenic systems. The substrate dictates flexibility, thermal stability, dielectric properties, and radiation resistance.

Substrate selection is vital for designing foldable GaN-based cryogenic electronic systems, affecting flexibility, thermal performance, and environmental durability. GaN films experience strain and potential microcracks when bent on flexible substrates. . Suitable substrates must bend while providing structural support and thermal stability at cryogenic temperatures. Polyimide (Kapton) is flexible and performs well down to 4 K but has limited thermal conductivity and radiation tolerance. Aluminum Nitride (AlN) has good thermal conductivity and radiation resistance but lacks flexibility, which can be improved with thin-film configurations. Polydimethylsiloxane (PDMS) is very flexible but becomes brittle below 40 K, suitable for low-risk applications. Balancing these factors is key to successful foldable GaN electronics.

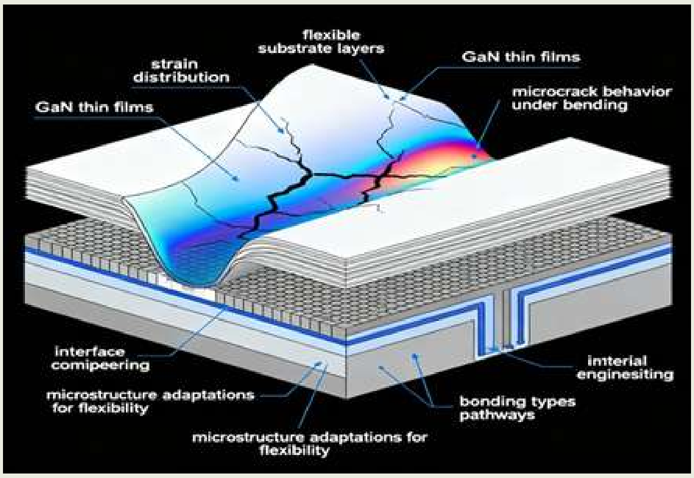

Figure 3 : GaN thin films on flexible substrates

Hybrid Substrates

Combining polyimide with AlN balances flexibility and thermal performance. These hybrids mitigate thermal mismatch, prevent nanocracks, and support long-term reliability.

5. Packaging and Reliability Strategies

Rigid-Flex Integration

GaN dice mounted on multilayer polyimide-ceramic substrates enable foldable half-bridge converters. These reduce stowage volume during launch and deploy compactly in orbit.

Adhesives and Encapsulants

Cryo-stable materials such as parylene and low-CTE epoxies improve interlayer adhesion. Radiation-hardened encapsulants further enhance durability.

Stress Relief Mechanisms

Hybrid stacks incorporate compliant buffer layers to absorb thermal stress. Patterned microstructures with compliant zones enhance fold endurance and reduce fracture propagation.

Reliability Assessment Protocols

- **Material Coupon Testing:** Substrates undergo >50 thermal cycles between 300 K and 4 K.
- **Device Characterisation:** Cryogenic probe stations measure leakage, mobility, and threshold drift.
- **Prototype Demonstration:** GaN half-bridge converters tested under cryogenic vacuum conditions.
- **Radiation Screening:** Flexible encapsulants exposed to up to 30 krad (Si) of gamma rays and protons.

6. Architectural Design Patterns

Key components in foldable GaN module design include:

Component	**Function**
GaN HEMTs	High-speed, high-efficiency switching
Integrated Gate Drivers	Minimise parasitics, improve performance
Flexible Interconnects	Enable folding during launch
Thermal Spreaders (AlN, DLC)	Dissipate heat in vacuum
Isolation Layers	High-voltage safety in space
Mechanical Hinges	Enable compact stowage and orbital deployment
EMI Shielding	Prevent interference and radiation damage
Locking Mechanisms	Ensure stability post-deployment

Table 1: Shows Key components with function in foldable GaN module design

7. Comparative Analysis

- GaN outperforms Si and SiC for foldable cryogenic modules:
- GaN – Excellent cryogenic operation, >1 MHz switching, good flexibility.

- SiC – Good cryogenic performance, lower flexibility.
- Si – Poor cryogenic performance, obsolete for such use.

Property	GaN	SiC	Si
Cryogenic Operation	Excellent	Good	Poor
Flexibility Integration	High (thin films)	Low	Very low
Switching Frequency	>1 MHz	~500 kHz	<100 kHz
Radiation Hardness	High	Moderate	Low

Table2: comparative Analysis of GaN, SiC and Si.

8. Current Challenges

1. Scalable GaN Growth on Flexible Substrates

Most GaN devices are fabricated on rigid substrates (Si, SiC, sapphire). Transfer printing of GaN nano-membranes and roll-to-roll processing show promise but require improvements in crystal quality and yield.

2. Radiation Hardness

Flexible polymers are prone to charge trapping and embrittlement under radiation. Solutions include radiation-hard passivation, metallic shielding, and GaN enhancement-mode devices.

3. Thermal Management

The absence of convection at cryogenic temperatures necessitates innovative solutions. Graphene-based spreaders, diamond-like carbon films, and hybrid AlN-polyimide layers improve heat dissipation.

4. Qualification Standards

Current NASA GEVS and ESA ECSS standards do not adequately cover foldable modules. New testing protocols must include flexural fatigue, fold-unfold endurance, and crack propagation monitoring.

5. Integration with Advanced Missions

ISRO's cryogenic upper stages, superconducting sensors, and quantum payloads demand foldable GaN solutions. Collaborative research is vital to tailor devices for these applications.

9. Conclusion

Foldable GaN electronics offer a revolutionary path for cryogenic space systems, combining wide-bandgap GaN device physics, flexible substrates, and thermal/radiation resilience. These systems are designed to withstand the extreme challenges of space ultra-low cryogenic temperatures, high radiation exposure, intense launch vibrations, and limited thermal dissipation while maintaining high power density and operational reliability. Their ability to fold compactly for launch and deploy efficiently in orbit makes them ideal for space-constrained missions such as quantum communication payloads, cryogenic propulsion units, and advanced astronomical sensors. Compared to silicon and silicon carbide, GaN devices provide superior cryogenic performance, faster switching speeds, and lower mass. The success of this technology relies on improvements in substrate engineering, radiation hardening, thermal management, and new standards, facilitating deep-space exploration.

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Do You Know ?

The story of semiconductors begins not in the 20th century with silicon chips and transistors, but much earlier in the age of Enlightenment.

In 1782, Italian physicist Alessandro Volta best known for inventing the voltaic pile (the first true battery) used the term "semiconducting" to describe the electrical behavior of certain materials. While the exact context of his usage is not widely documented, it marked a conceptual recognition that some substances exhibited electrical properties distinct from both conductors and insulators.

This was decades before the formal understanding of electrons, band theory, or solid-state physics. Volta's observations were rooted in empirical experimentation, and his terminology hinted at the nuanced behavior of materials like silver sulfide and copper oxide, which would later be classified as semiconductors.

Early Observations of Semiconductor Behavior

1833 – Michael Faraday observed that the resistance of silver sulfide decreased with temperature—unlike metals, whose resistance increases. This was one of the first documented semiconductor effects.

1851 – Johann Hittorf conducted quantitative studies on the conductivity of Ag_2S and Cu_2S, further establishing the anomalous behavior of these materials.

1874 – Karl Ferdinand Braun discovered rectification in metal sulfides, laying the groundwork for point-contact diodes and early radio detectors.

Before the Transistor: A Century of Discovery

These early findings were crucial in shaping the understanding of semiconductors long before the invention of the transistor in 1947. The term "semiconductor" evolved from descriptive observations to a foundational concept in solid-state physics, culminating in the development of:

Crystal rectifiers, Photoresistors, Thermistors, and eventually, transistors and integrated circuits.

Advanced 2D Material Semiconductors & Electronic Devices

Poonam Borhade, PhD, Postdoctoral Fellow
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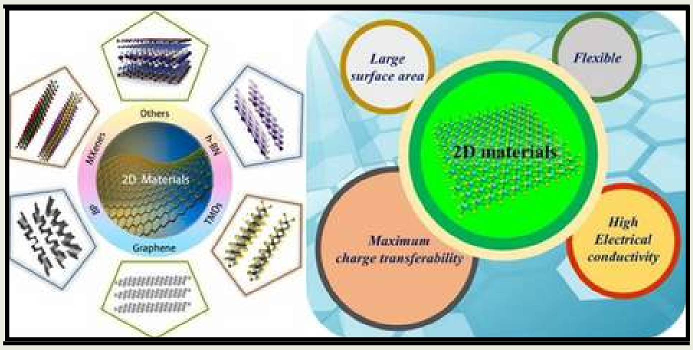
1. What Are 2D Semiconductors?

Two-dimensional (2D) materials—crystals just atoms thick—are transforming electronics. Unlike bulk semiconductors, these offer:

- **Atomic-scale, layered materials** with distinct properties depending on the number of layers. Most promising candidates include TMDCs like MoS_2, WS_2, WSe_2, and phosphorene. Atomic scale thickness enables ultimate electrostatic control in transistors.
- **Moderate and Tunable bandgaps** depending on layer and composition (e.g., ~1.8 eV for MoS_2)[9] is ideal for efficient digital switching—and superior electrostatic control owing to their atomically thin nature.
- **Remarkable mechanics**—flexible, strong, and suitable for wearable electronics.



Schematic of 2D Semiconductor Materials and their properties[1, 2].

Key families include:

- **TMDs** (e.g., MoS_2, WSe_2): semiconducting
- **Graphene & bilayer graphene:** metallic or tunnel FET channels
- **Phosphorene:** high mobility flexible transistors (~310 cm^2/Vs)
- **MXenes:** metallic conductors, ideal for sensing/interconnects

Possessing unique electronic, optical, and mechanical traits, 2D materials present future pathways in logic, sensing, neuromorphic, and quantum devices.

2. Fabrication & Integration Techniques

2.1 Synthesis & Layer Transfer

- **Large-area synthesis** via **PVD, CVD/MOCVD growth** enables wafer-scale films; integration onto 300 mm wafers achieved via templated growth and photonic debonding, yielding>99.5% uniform monolayers. CMOS-compatible methods are gaining traction.
- **Wafer-scale transfer:** Techniques like templated growth and photonic debonding allow integration onto 300 mm wafers. Artifacts like wrinkles and bubbles remain key defects during transfer[3].
- **Contact engineering:** Low-resistance interfaces achieved via graphene/2D metal contacts, phase engineering, or semi-metal integration to reduce Fermi- level pinning.

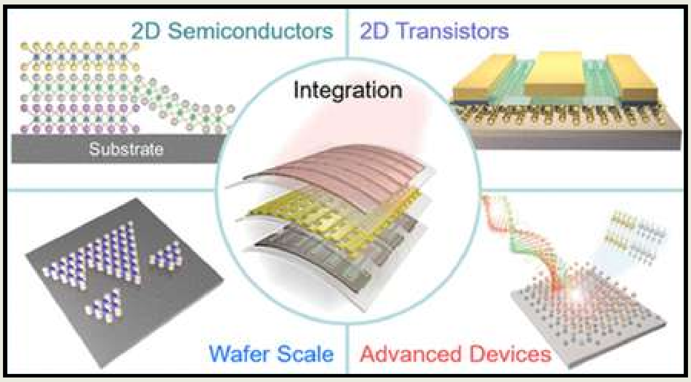
2.2 Device Architectures, Integration and Milestones

- **Transistor performance:** First monolayer MoS_2 FETs emerged in 2011.
- **Recent Gate-all-around (GAA) and nanosheet FETs** fabricated with monolayer MoS_2, achieving I_{on} ≈451 μA/μm and on/off ratio $>10^9$.
- **Complex logic circuits:** Integrated inverters, NAND gates, SRAM, and ring oscillators based on MoS_2 date back to 2012.
- **Beyond CMOS:** Innovations like bilayer graphene tunnel-FETs enable ultra- low voltage operation (<150 mV).
- **p-FETs** with WSe_2 on 300 mm wafers demonstrated by imec & Intel.

2.3 Contact & Metrology

- Dual-gate designs improve electrostatic control.
- Metrology tools are being refined for structural, electrical, and chemical characterization to support

industrial adoption[4].

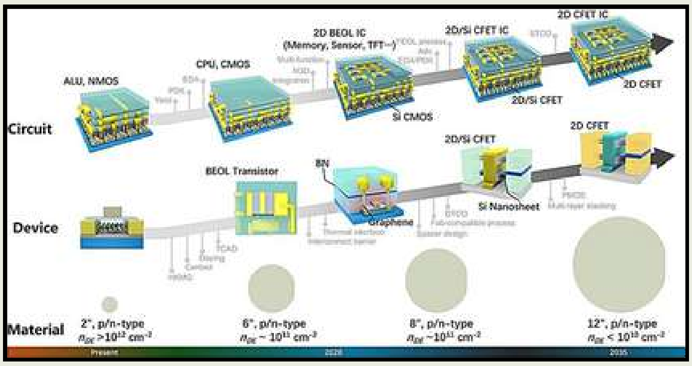


2D materials growth, wafer scale transfer, Device Architecture, Integration and Contacts[5]

3. 2D Electronics Roadmap Toward Large-Scale Adoption

Key Roadmap Milestones

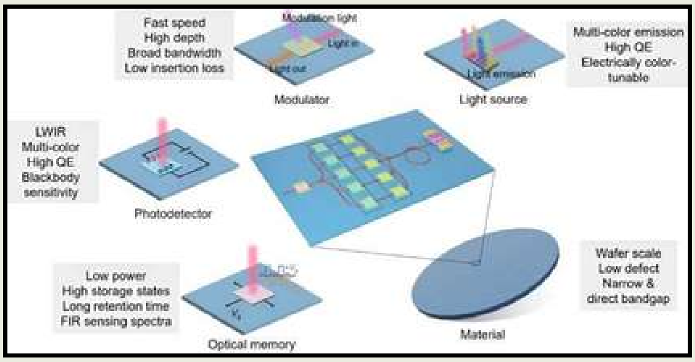
Timeframe	Milestone
2024-2026	Establish high-quality wafer-scale growth/synthesis, templated transfers, contact and dielectric integration, planar 2D-FET prototype circuits
2026–2030	Adopt stacked 2D nanosheet transistors, integration in BEOL, scale logic circuits and flexible sensor chips, hybrid CMOS-2D prototypes, integrate AI/quantum architectures
2030–2035	3D stacking of 2D nanosheets, neuromorphic units, valley/quantum devices
2035+	Full 3D packaging, integrated flexible sensors, optoelectronic/quantum hybrid chips, heterogeneous 2D systems; in-system sensing + neuromorphic co-design; scalable manufacturing pathways



Roadmap for the 2D information materials development (Credit: Science China Press)

Driving Domains

The journey is structured into three major domains:



Roadmap for the future development of 2D optoelectronics (Credit: Science China Press)

1. **More-Moore:** Continued scaling via stacked nanosheet transistors. Extending Moore's Law via ultrathin, high-performance 2D transistors in digital logic.
2. **More-Than-Moore:** Smart, low-power flexible sensing CHIPS with on-board processing and IoT devices.
3. **Beyond-Moore:** Pushing into neuromorphic, quantum logic, terahertz computing and optoelectronic devices

4. Device Applications & Architectures

4.1 Advanced Digital Logic (More-Moore)

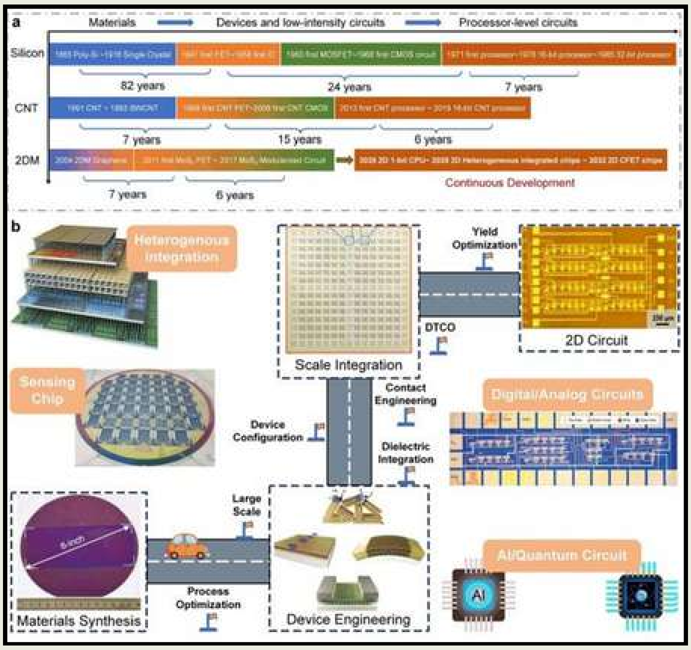
- 2D FETs mitigate short-channel effects beyond 3 nm, enabling continued scaling in gate-length and 3D GAA nanosheets.
- imec's roadmap suggests planar 2D-FETs first in BEOL, later stacked in more complex nanosheet architectures

4.2 Flexible Sensors& "More-Than-Moore"

- Flexible sensors for pressure, chemicals, biosignals demonstrated with arrays since 2007. Arrays of temperature, pressure, chemical, pH, and ion sensors built on 2D materials show promise in IoT, health monitoring, and smart wearables.
- Roadmap for flexible sensor chips: from rigid → soft/stretchable → full flexible → integrated smart sensor systems(2025-2032)[6].

4.3 Neuromorphic, Memory & Optoelectronic Devices

- Heterostructures (TMD + h-BN, IV-VI semiconductors) emulate synapse behavior. Optoelectronic synapses using vertical or planar



Schematic diagram of the general roadmap for 2D circuits. (a) Development timeline of silicon-based, carbon nanotube-based, and 2D ICs. (b) Route for the realization of 2D circuits and possible application in the future.

heterostructures (e.g., TiS_3, MoS_2/In_2Se_3, MoS_2/h-BN) emulate synaptic plasticity.

- **MOD-PC:** WSe_2-based optoelectronic neuromorphic cell; mimics synaptic learning in a compact, energy-efficient chip[7].

4.4 Quantum & Valleytronics

- Bilayer graphene tunnel-FETs operate at <150 mV switching voltages
- Valleytronics in TMDs enables new bit-encoding schemes via crystal momentum states
- Recent quantum materials like 1T-TaS_2 show light

5. Challenges & Research Directions:

5.1 Material Uniformity & Quality

- Large-area, defect-free growth is still elusive; target defect density is $\sim 10^{10}$ cm^{-2}[8].

5.2 Contact Resistance & Performance

- Low-resistance contacts (~10 Ω·µm) are critical; progress in phase-engineering and semi-metal interfaces

5.3 Thermal & Integration Issues

- Managing mixed signals, heterogeneous materials, and 3D packaging requires cross-disciplinary solutions.
- 3D stacked architectures face heat dissipation and interconnect RC delays— new approaches in bonding and thermal vias required.

5.4 Metrology & Standardization

- Robust tools for structural-electrical mappingand industry-standard metricsare urgently needed

5.5 Mobility limitations

- MoS_2 mobility (30–60cm²/Vs) is still lower than Si, restricting sub-10 nm scaling.

6. Conclusion

2D semiconductors stand poised to revolutionize electronics through a three-pronged roadmap: ultra-scaled logic transistors, flexible smart sensors, and advanced neuromorphic/quantum devices. Significant advances in wafer-scale integration (e.g., imec's 300 mm transfers), device demos (WSe_2 FETs, MOD-PC), and emerging quantum components (1T-TaS_2) point to a paradigm shift in the next decade. However, addressing challenges in material uniformity, contact engineering, thermal management, and metrology will be critical. With industry–academia collaboration, 2D materials could truly deliver "More Moore", "More-Than-Moore", and "Beyond Moore" capabilities.

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Astronomy: Ground and Space-based Telescopes

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आपण डोळ्यांनी जे काही पाहतो ते optical wavelength मध्ये बघतो, ज्याला visible band असेही म्हणतात. जसं डोळ्यांनी किती दूरपर्यंत स्पष्ट पाहता येतं याला मर्यादा आहेत, तसंच आपण डोळ्यांनी काय काय पाहू शकतो यालाही मर्यादा आहेत. उदाहरणार्थ, रात्री आपल्याला torch शिवाय दिसत नाही, पण काही प्राण्यांना रात्री सहज दिसतं. आपल्या शरीरातील हाडांना पाहण्यासाठी आपल्याला X-ray काढावा लागतो. थंड पदार्थ गरम करण्यासाठी आपण microwave oven वापरतो. उन्हात जाताना ultraviolet rays पासून वाचण्यासाठी आपण suncoat घालतो किंवा sun cream लावतो. ह्यात उल्लेख केलेल्या X-rays, microwaves, आणि ultraviolet rays आपल्याला डोळ्यांनी दिसत नाहीत. रात्री आकाशात दिसणारे तारे आपल्याला optical waves मुळे दिसतात. पण हेच objects इतरही waves मध्ये दिसू शकतात—जसे की X-ray, Ultraviolet, Infrared, आणि Radio waves आणि या सर्व waves पाहण्यासाठी आपल्याकडे योग्य प्रकारच्या दुर्बिणी (telescopes) उपलब्ध आहेत.

मग तुम्ही असंही विचाराल की, एकाच दुर्बिणीतून ह्या सर्व waves पाहता येतात का? आणि काही दुर्बिणी space मध्येच का असतात तर काही ground वरच का असतात? याचाच वेध आपण या लेखात घेणार आहोत.

आपण डोळ्यांनी पाहू शकणाऱ्या आणि न पाहू शकणाऱ्या अशा एकूण 7 प्रकारच्या waves असतात, ज्यांना एकत्रितपणे Electromagnetic Spectrum म्हणतात. हे प्रकार म्हणजे— 1. Gamma-ray, 2. X-ray, 3. Ultraviolet, 4. Visible (optical), 5. Infrared, 6. Microwave, 7. Radio (Fig-1).

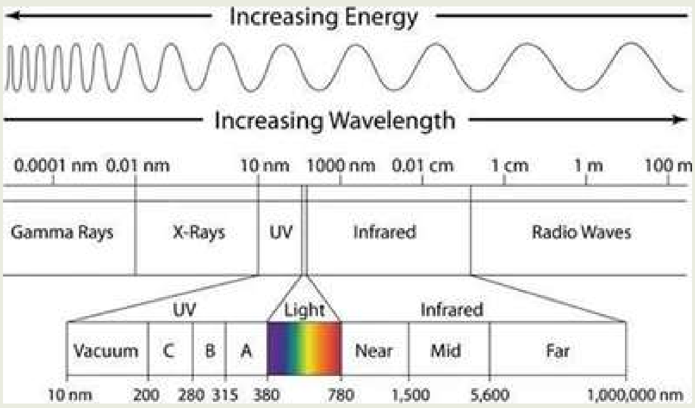

Fig-1: Electromagnetic Spectrum.
Credit: https://apniphysics.com/

जसे ह्या waves आपल्या रोजच्या वापरात असतात, तसंच सूर्य, तारे, दीर्घिका (galaxy), nebulae यांसारखे अवकाशातील घटकही ह्या waves उत्सर्जित करत असतात. मात्र, आपल्या पृथ्वीचं वातावरण ह्या सर्व waves आत येऊ देत नाही. जीवनासाठी हानिकारक असलेल्या high energy waves ना पृथ्वीचं वातावरण एकतर absorb करतं किंवा reflect करतं.

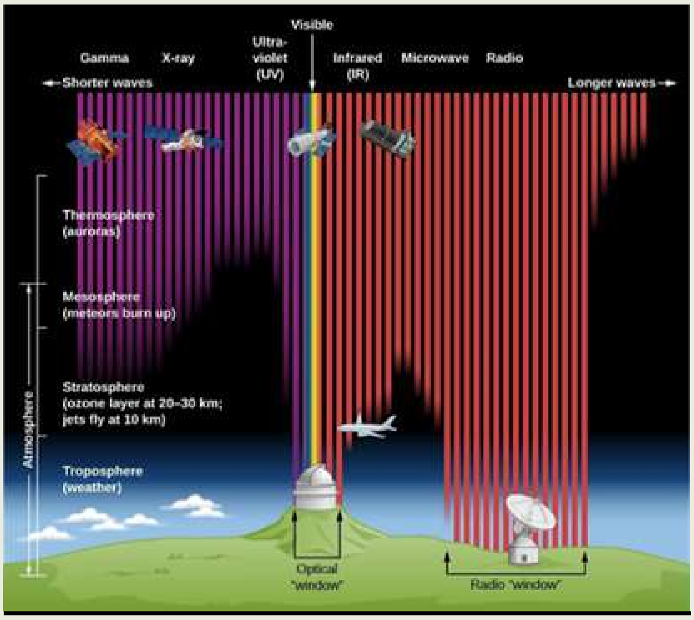

Fig-2: Electromagnetic Atmospheric Window.
Credit: Astronomy-OpenStax.

Fig-2 मध्ये दाखवलेली Electromagnetic Atmospheric Window स्पष्ट करते की काही विशिष्ट wavelengths फक्त जमिनीवरून पाहता येतात, तर काही waves फक्त space मधूनच पाहता येतात. त्यामुळे telescope हा एकतर ground-based असतो किंवा space-based.

जमिनीपर्यंत फक्त optical आणि radio waves पोहोचू शकतात, म्हणून ground-based telescope मुख्यतः Radio आणि Optical Telescopes असतात. समुद्रसपाटीपासून खूप उंचावर जाऊन आपण काही near-infrared (NIR) waves सुद्धा observe करू शकतो. मात्र mid आणि far infrared waves पाहण्यासाठी आपल्याला space telescope ची गरज लागते. Infrared waves या optical telescope मधूनच observe केल्या जातात, पण त्यांना detect करण्यासाठी वेगळे infrared cameras वापरावे लागतात.

तर, एकाच दुर्बिणीतून सर्व waves पाहता येतात का? तर नाही. कारण दुर्बिणीच्या आरशाचा व्यास हा त्या wave च्या wavelength च्या तुलनेत समान किंवा मोठा असावा लागतो, तेव्हाच ती wave reflect होऊ शकते.

उदाहरणार्थ, radio waves ची wavelength ही मीटर इतकी लांब असते, त्यामुळे त्यांना reflect करण्यासाठी तितक्याच लांबीचा आरसा लागतो. जर 1 मीटर wavelength ची wave आपण 0.5 मीटर लांबीच्या आरशावर टाकली, तर ती आरपार जाईल—reflect होणार नाही. म्हणूनच radio waves गोळा करण्यासाठी मोठ्या antenna dishes वापरल्या जातात. Radio telescopes हे अनेक antenna dishes च्या array ने बनलेले असतात. भारतातील GMRT (Giant Metrewave Radio Telescope) हा 30 किलोमीटर परिसरात Y-आकारामध्ये रचलेला पसरलेला आहे. यामध्ये प्रत्येकी 45 मीटर व्यासाचे 30 antenna dishes आहेत. ह्या सर्व dishes एकसंध radio telescope म्हणून काम करण्यासाठी interferometry ही technique वापरली जाते. GMRT मध्ये dish-to-dish अंतरामुळे जास्तीत जास्त interferometry baseline सुमारे 25 किलोमीटर आहे.

पहिली black hole (M87) ची image ही पृथ्वीवरील 8 radio telescopes वापरून मिळवली गेली होती. ज्यात interferometry baseline ही पृथ्वीच्या व्यासाइतकी म्हणजे सुमारे 12,742 किलोमीटर होती. हीच baseline अजून वाढवण्यासाठी आणि अधिक resolution मिळवण्यासाठी space radio telescope ची मदत घेतली जाते.

दुसरीकडे, optical waves ची wavelength ही radio waves पेक्षा कितीतरी पटीने कमी असल्यामुळे optical telescope चा mirror comparatively लहान असतो—साधारणतः 1 ते 30 मीटर च्या range मध्ये. त्यामुळे radio waves ह्या optical telescope मधून बघू शकत नाही.

Ultraviolet waves या optical telescope च्या design मध्ये गोळा करता येतात, पण त्या waves पृथ्वीच्या वातावरणात शोषले होतात, त्यामुळे त्यांना पाहण्यासाठी space telescope ची आवश्यकं असतं. तसेच, X-ray आणि gamma-ray waves सुद्धा पृथ्वीच्या वातावरणात शोषले किंवा विखुरले जातात म्हणून त्यांनाही पाहण्यासाठी आपल्याला space telescope चीच गरज पडते. तसेच या waves इतक्या energetic असतात की त्या पारंपरिक optical telescope मधून पाहता येत नाहीत. त्या reflect होत नाहीत आणि त्यांना focus करण्यासाठी विशेष प्रकारचे optical design लागतात.

Gamma-rays जमिनीवरून थेट पाहता येत नाहीत, कारण त्या पृथ्वीच्या वातावरणात प्रवेश करताच interact होतात आणि नष्ट होतात. त्यामुळे त्यांना अप्रत्यक्ष पद्धतीने पाहावे लागते. जेव्हा gamma-ray वातावरणात प्रवेश करतो, तेव्हा तो secondary particles चा एक shower तयार करतो—याला extensive air shower म्हणतात. या energetic particles च्या हालचालीमुळे वातावरणात एक विशिष्ट प्रकारचा प्रकाश निर्माण होतो, ज्याला Cherenkov light म्हणतात. हा प्रकाश अत्यंत क्षणिक आणि धूसर असतो, पण तो Cherenkov detectors किंवा Imaging Atmospheric Cherenkov Telescopes (IACTs) वापरून पाहता येतो. उदाहरणार्थ, H.E.S.S., MAGIC, आणि VERITAS हे प्रमुख ground-based gamma-ray observatories आहेत, जे अशा Cherenkov light चा वापर करून gamma-ray sources चा अभ्यास करतात. Cherenkov light हे त्या particles च्या

वेगामुळे निर्माण होतो, जेव्हा ते प्रकाशाच्या तुलनेत जास्त वेगाने माध्यमातून जातात—जसं की आपले वातावरण. त्यामुळे gamma-ray ची दिशा, energy, आणि source location याचा अंदाज लावता येतो.

आतापर्यंत आपण यावर चर्चा केली की आपल्याला दिसणाऱ्या आणि न दिसणाऱ्या waves पाहण्यासाठी आपल्याकडे त्या-त्या wavelengths साठी कोणकोणत्या विशिष्ट प्रकारच्या दुर्बिणी उपलब्ध आहेत. पण मग प्रश्न असा निर्माण होतो—आपल्याला इतक्या वेगवेगळ्या दुर्बिणींची गरज तरी का पडते?

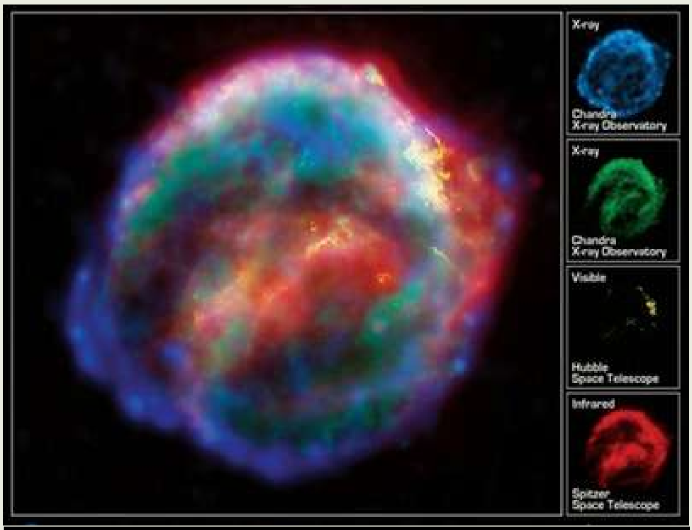

Fig-3: Supernova Remnant SN 1604.
Credit: Nasa, ESA/ JPL-Caltech.

Fig-3 मध्ये Supernova Remnant हा वेगवेगळ्या wavelengths मध्ये कसा दिसतो हे दाखवले आहे. Optical/visible light मध्ये त्याचा फक्त एक छोटा भाग दिसतो, तर इतर wavelengths मध्ये त्याचा अधिक विस्तृत भाग दिसतो आणि प्रत्येक wavelength मध्ये त्याचे structure वेगळं दिसतं. म्हणजेच, प्रत्येक wavelength च्या window मधून त्या object चे वेगवेगळे भाग दिसू शकतात. जो भाग ज्या wavelength मध्ये emit करत असेल, तो भाग आपण त्या wavelength मध्येच पाहू शकतो.

त्याचप्रमाणे Fig-4 मध्ये सूर्य वेगवेगळ्या wavelengths मध्ये कसा दिसतो हे दाखवले आहे. सूर्याच्या मुख्यतः तीन layer असतात—Photosphere, Chromosphere, आणि Corona.

1. Photosphere आपल्याला visible light मध्ये दिसतो.
2. Chromosphere हा UV/extreme UV मध्ये दिसतो.
3. आणि Corona मुख्यतः X-ray मध्ये दिसतो.

म्हणजेच, सूर्याचं संपूर्ण रूप समजून घ्यायचं असेल तर आपल्याला वेगवेगळ्या wavelength मध्ये निरीक्षण करावे लागते.

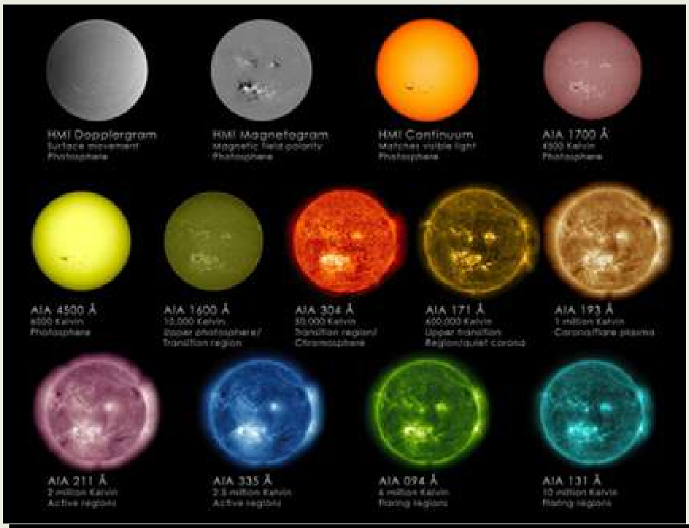

Fig-4: Sun in Different Wavelengths.
Credit: NASA/SDO/Goddard Space Flight Center

अशाच प्रकारे इतर अवकाशातील objects देखील विविध प्रकारच्या waves मध्ये उत्सर्जित करतात. त्यामुळे त्या प्रत्येक wave ला पाहण्यासाठी वेगवेगळ्या प्रकारच्या दुर्बिणींची आवश्यकता असते. एकाच दुर्बिणीतून सर्व wavelength पाहता येत नाहीत, कारण प्रत्येक wave साठी वेगळी आणि विशिष्ट प्रकारची optical design आणि detector technology लागते. तसेच सर्व ground-based telescope हे space-based पण असू शकतात. फक्त त्याला काही मर्यादा येतात त्या मोठ्या आकाराच्या दुर्बिणी अवकाशात पाठवताना येणाऱ्या limitations मुळे.

Ground-based Telescopes:

1. Radio Telescope
2. Near Infrared and Optical Telescope
3. Microwave Telescope
4. Gamma-ray Telescope

Space-based Telescopes:

1. X-ray Telescope
2. Gamma-ray Telescope
3. Infrared, Optical/UV Telescope
4. Radio Telescope

Weblinks:

1. https://public.nrao.edu/telescopes/radio-telescopes/
2. https://science.nasa.gov/mission/spitzer/
3. https://chandra.harvard.edu/
4. https://fermi.gsfc.nasa.gov/
5. https://magic.mpp.mpg.de/

Perception, Holography and the Illusion of Time

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1. Abstract

This article presents a philosophical and conceptual inquiry into the nature of perception, time delay and holography. Drawing upon ideas from neuroscience, physics and cognitive success, it proposes that our conscious experience of the world may be delayed, processed projection which is similar to the structure and behavior of a hologram. By investigating the time lag on sensory processing and by comparing it to the holographic principle in physics, the paper offers a perspective where reality as perceived is not immediate or complete but a constructed echo raising profound questions about the nature of existence and awareness.

2. Acknowledgement

This paper is inspired by personal reflections and curiosity, as well as support from AI tools and open resources.

3. Introduction

Perception is the brain's way of interpreting signals from the environment. Holography, a physical phenomenon, creates the illusion of a three-dimensional image from a two-dimensional pattern. The idea presented here asks: Can the way we perceive the world be similar to the way holograms function? Are we interpreting interference patterns as solid reality, and are we possibly experiencing a delayed version of events due to the finite speed of light and neural processing?

4. Perception Is Delayed: Neuroscience Insight

In the field of neuroscience, it is well established that the brain takes approximately 80-100 milliseconds to process sensory data and form a conscious perception. Every sensory input undergoes a delay before it is processed by the brain. For instance, light takes time to travel from objects to our eyes, and neural transmission takes milliseconds. This implies that we are always experiencing events a fraction of a moment after they occur. This delay, combined with the brain's reconstruction of input, might suggest that what we experience as the 'present' is in fact the past-similar to how a hologram represents something that isn't actively present.

5. The Holographic Principle in Physics

The holographic principle, which is introduced by Gerard 't Hooft and expanded by Leonard Susskind, proposes that all the information contained in a 3D volume of space can be encoded on a 2D surface like a hologram. In my perspective, our universe might be a projection from a deeper and hidden layer of reality. The same way a 3D hologram is built using light waves and interference patterns, our experience might be a holographic projection based on encoded information at the boundaries of space-time.

6. Hypothesis: Are We Experiencing a Holographic Past?

If holography uses light to encode and recreate an image from interference, and if the brain reconstructs perception from incomplete signals, then perhaps our reality is constructed similarly. Our experience of the present may be a holographic reconstruction based on light patterns and memory, delayed by both physics and biology. This raises a thought-provoking question: Are we ever truly in the 'now', or only in a constructed version of it?

7. Are intelligent systems also trapped in a kind of illusion like humans?

As we move toward a future deeply integrated with Artificial Intelligence, this question often comes up. AI systems do not see reality directly. They perceive only data inputs-numbers, pixels, texts processed through algorithms. Just as we humans rely on the delay of light and neural processing, AI also relies on the delay and limitation of its training data. Just as our brains construct a world-model using light and time, AI builds a data-world using past input. It does not know what is truly happening in the present moment or in the world outside its training but predicts, simulates, and responds to what it thinks reality is-just like the human brain.

8. Implications

This idea is not just poetic, it is also rooted in scientific findings. If perception is delayed and if the universe truly follows holographic encoding, our conscious experience may be an illusion crafted by both physics and biology. This could also connect with theories of simulation, quantum information, and even explain phenomena like Deja vu, consciousness outside of time, or changed states of awareness. More than anything, this approach will encourage students and thinkers to view perception as a subject of physics and not just psychology. And also to blur the boundary between observer and observed.

9. Conclusion

We may not directly see the world as it is. We see a model of it which is created by our brain, shaped by biology, might be filtered by consciousness and potentially grounded in holographic physics. If we explore this intersection of optics, time, perception, and physics, it could open up revolutionary perspectives in science.

TRIVIA

Do You Know ?

- Semiconductors are being tailored for artificial intelligence workloads, with architectures designed for faster neural processing and lower energy consumption.
- Materials like gallium nitride (GaN) and silicon carbide (SiC) are enabling high-efficiency power electronics, especially in electric vehicles and renewable energy systems.
- Chipmakers are pushing boundaries with 2-nanometer nodes, packing billions of transistors into ultra-small footprints for unmatched performance and energy efficiency.
- Vertical integration of chips (3D stacking) is revolutionizing memory and logic density, reducing latency and improving bandwidth in compact designs.
- Sustainable Manufacturing Companies are adopting greener fabrication methods, including water recycling, low-emission materials, and energy-efficient cleanrooms.
- Research into quantum semiconductors and brain-inspired neuromorphic chips is accelerating, promising breakthroughs in computing paradigms.
- Extreme ultraviolet (EUV) lithography is now mainstream, allowing finer patterning and enabling next-gen chip miniaturization.
- Semiconductors are being embedded directly into edge devices—from drones to wearables—enabling real-time processing without cloud dependency.
- Automotive Semiconductors Chips designed for autonomous driving, vehicle-to-everything (V2X) communication, and smart sensors are reshaping mobility tech.
- Modular chiplets allow flexible integration of specialized functions, improving scalability and reducing design complexity.

सेमीकंडक्टर्समधून फील्ड इलेक्ट्रॉन उत्सर्जन

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फील्ड इलेक्ट्रॉन उत्सर्जन (Field Electron Emission): ईथे चालू असलेले संशोधन प्रामुख्याने फील्ड इलेक्ट्रॉन उत्सर्जन घटनेवर केंद्रित आहे, जे सात दशकांहून अधिक काळ अभ्यासाचा एक महत्त्वाचे क्षेत्र आहे, आणि असंख्य संशोधक त्याच्या संशोधनासाठी बराच वेळ देत आहेत. ही आवड अलिकडच्या तांत्रिक प्रगतीमुळे निर्माण झाली आहे, कारण अनेक आधुनिक उपकरणांना कार्यक्षम इलेक्ट्रॉन स्रोतांची आवश्यकता असते. यामध्ये स्मार्टफोन, टेलिव्हिजन आणि लॅपटॉप सारख्या दैनंदिन वापराच्या गॅझेट्स तसेच एक्स-रे ट्यूब, फील्ड इलेक्ट्रॉन स्कॅनिंग इलेक्ट्रॉन सूक्ष्मदर्शक आणि फील्ड इलेक्ट्रॉन टनेलिंग इलेक्ट्रॉन सूक्ष्मदर्शक इत्यादीं इलेक्ट्रॉन मायक्रोस्कोप सारखी अत्याधुनिक संशोधन उपकरणे समाविष्ट आहेत.

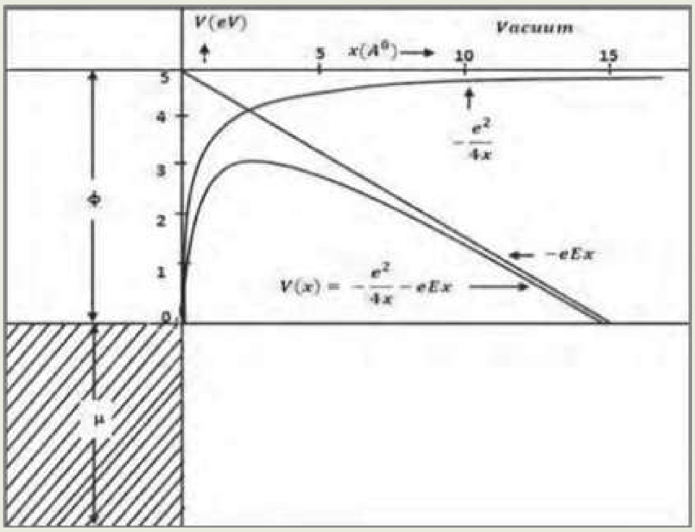
थर्मिओनिक उत्सर्जन, फोटोइलेक्ट्रॉन उत्सर्जन, दुय्यम इलेक्ट्रॉन उत्सर्जन आणि फील्ड इलेक्ट्रॉन उत्सर्जन यासह अनेक यंत्रणांद्वारे इलेक्ट्रॉन बाहेर काढले जाऊ शकतात. इतर प्रक्रियांप्रमाणे, फील्ड इलेक्ट्रॉन उत्सर्जनला बाह्य ऊर्जा स्रोताची आवश्यकता नसते. त्याऐवजी, धातू किंवा अर्धवाहकातून मजबूत इलेक्ट्रोस्टॅटिक क्षेत्राच्या प्रभावाखाली क्वांटम मेकॅनिकल टनेलिंगद्वारे इलेक्ट्रॉन उत्सर्जित केले जातात. ही घटना प्रथम १८९७ मध्ये घन पृष्ठभागावरून आर. डब्लू. वुड यानी पाहिली.

क्षेत्र उत्सर्जनातून बाहेर पडणारे इलेक्ट्रॉन उत्सर्जक पृष्ठभागावरून जास्त ऊर्जा वाहून नेत नाहीत, कारण सर्व उत्सर्जित इलेक्ट्रॉन फर्मी (धातू मध्ये इलेक्ट्रॉन जिथपर्यंत भरलेले असतात) पातळी किंवा त्याच्या आसपासच्या भागातून उद्भवतात. तथापि, क्षेत्राची ताकद वाढत असताना, फर्मी पातळीच्या खालून मोठ्या संख्येने इलेक्ट्रॉन बोगद्यात येऊ शकतात.

क्षेत्र उत्सर्जन सिद्धांत: क्वांटम मेकॅनिकल टनेलिंगचा मूलभूत सिद्धांत, जो सपाट धातूच्या पृष्ठभागावरून व्हॅक्यूममध्ये (निर्वात जागा) इलेक्ट्रॉनच्या वहनाचे वर्णन करतो, तो प्रथम १९२८ मध्ये आर. एच. फाउलर आणि एल. नॉर्डहाइम यांनी मांडला होता. यामुळे फाउलर-नॉर्डहाइम समीकरण सुप्रसिद्ध झाले आहे, जे F-N समीकरण आहे. कोणत्याही सुधारक घटकाची भर न घालता अचूक त्रिकोणी अडथळ्याचे योजनाबद्ध प्रतिनिधित्व खालील आकृतीमध्ये दाखवले आहे आणि ते असे दिले आहे

$$J = 6.2\times10^{6}\frac{\left(\mu/\phi\right)^{1/2}}{(\mu+\phi)}E^{2}\exp\left[-6.8\times10^{7}\frac{\left(\phi^{3/2}\right)}{(E)}\right](amp/cm^{2}) \quad \text{-----(1)}$$

eV मध्ये व्यक्त केलेल्या सर्व ऊर्जेसाठी आणि E हे V/cm मध्ये आहे. φ हे धातूचे वर्कफंक्शन (इलेक्ट्रॉन ला निर्गमित करन्यास लागणारी ऊर्जा) आहे, μ ही फर्मी ऊर्जा आहे आणि J ही उत्सर्जन प्रवाह घनता आहे जी A/cm2 मध्ये मोजली जाते.



आकृती १: इलेक्ट्रॉनच्या पृष्ठभागापासूनच्या अंतराच्या (x) कार्याच्या रूपात त्याच्या स्थितीज ऊर्जेचे योजनाबद्ध प्रतिनिधित्व (प्रमाणानुसार नाही).

समीकरण (१) मध्ये व्यक्त केलेली व्युत्पत्ती संभाव्य ऊर्जा अडथळ्याच्या त्रिकोणी वर्तनाचा विचार करताना मिळते. पृष्ठभागावरील इलेक्ट्रॉनिक चार्ज घनता समाप्त होणाऱ्या धातूच्या सीमा/पृष्ठभागावर अचानक नाहीशी होत नसल्यामुळे, संभाव्य अडथळा डेल्टा फंक्शनप्रमाणे काटेकोरपणे उभा असू शकत नाही. याव्यतिरिक्त, प्रतिमा बल संभाव्यता संबंधित प्रतिमा संभाव्य संज्ञा Vx द्वारे पृष्ठभाग संभाव्य अडथळा कमी करते.

$$\therefore V_x = -\frac{e^2}{4x} \quad \text{-----(2)}$$

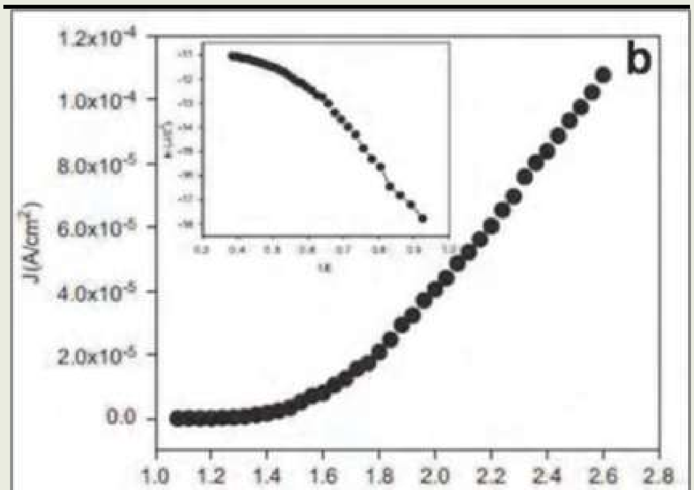
जिथे e हा इलेक्ट्रॉनिक चार्ज आहे आणि x हा धातूच्या

पृष्ठभागापासूनचे अंतर आहे. दुरुस्त केलेले **F-N** समीकरण असे परिभाषित केले आहे:

$$J = 6.2\times10^{6}\frac{\left(\mu/\phi\right)^{1/2}}{\alpha^{2}(\mu+\phi)}E^{2}\exp\left[-6.8\times10^{7}\frac{\phi^{3/2}\alpha}{E}\right] \quad \text{-----(3)}$$

जिथे, α हा प्रतिमा सुधारणा पद आहे. या प्रकरणात, ग्राउंड स्टेट एनर्जी ही कंडक्शन बँडच्या तळाशी $(\mu + \varphi)$ मानली जाते. धातूच्या पृष्ठभागावरून इलेक्ट्रॉन टनेलिंगसाठी **F-N** समीकरणाचे व्यापक सूत्रीकरण आणि व्युत्पत्ती विद्यमान साहित्यात उपलब्ध आहे. (गोमर, १९६१; फॉलर आणि नॉर्डहाइम, १९२८; मोडिनोस, १९८४).

सेमीकंडक्टरमधून फील्ड उत्सर्जन: सेमीकंडक्टरमधील फील्ड इलेक्ट्रॉन उत्सर्जनचा सिद्धांत अत्यंत गुंतागुंतीचा आहे, कारण तो प्रभावी इलेक्ट्रॉन वस्तुमान, फील्ड पेनिट्रेशन, पृष्ठभागाची अवस्था, अशुद्धता सांद्रता (डोपिंगचा n-प्रकार असो किंवा p-प्रकार असो), आणि बँड स्ट्रक्चर यासारख्या विविध घटकांना विचारात घेतो. स्ट्रॅटन (१९६२) हे सेमीकंडक्टरमधील इलेक्ट्रॉन उत्सर्जनावर फील्ड पेनिट्रेशन आणि पृष्ठभागाची अवस्था यांचा प्रभाव तपासणारे पहिले संशोधक होते, त्यांनी हे अधोरेखित केले की फील्ड इलेक्ट्रॉन उत्सर्जन वैशिष्ट्यांमधील प्रमुख घटक फील्ड पेनिट्रेशनपेक्षा तापमान आहे. नंतर, बास्किन (१९७१) यांनी n-प्रकारच्या सेमीकंडक्टरच्या फील्ड इलेक्ट्रॉन उत्सर्जन वर्तनाचा तपास केला, वहन बँडमधून फील्ड उत्सर्जनावर लक्ष केंद्रित केले. या सिद्धांताची अधिक तपशीलवार चर्चा मोडिनोस (१९८४) मध्ये आढळू शकते.



आकृती २: उपयोजित क्षेत्र लागू केल्यावर सेमीकंडक्टर (झिंक ऑक्साइड नॅनोवायर) मधून फील्ड इलेक्ट्रॉन विद्युतधारा घनता उत्सर्जन. (आकृती अंतर्गत: एफ-एन प्लॉट) अल्ट्रामायक्रोस्कोपी (जमाली शेनी, २००९) मधून पुनरुत्पादित कॉपीराइट © २००९. एल्सेव्हियर

२००७ मध्ये रिचर्ड फोर्ब्स आणि जे. एच. बी. डीन यांनी त्याच्या मूलभूत तत्त्वांचा आढावा घेतला तेव्हा फाउलर-नॉर्डहाइम (**F-N**) टनेलिंग सिद्धांतात लक्षणीय सुधारणा करण्यात आल्या. त्यांच्या सुधारणांमुळे अधिक रेषीय **F-N** कथानक तयार झाले. त्यानंतर, २००८ मध्ये, फोर्ब्सने विद्युत्-व्होल्टेज वैशिष्ट्यांसाठी एक अनुभवजन्य सूत्र तयार केले, ज्यामुळे फील्ड इलेक्ट्रॉन उत्सर्जनाची सैद्धांतिक चौकट आणखी वाढली.

F-N सिद्धांताचा नॅनोमटेरियल्समधून फील्ड उत्सर्जनावर उपयोग: आधी सांगितल्याप्रमाणे, फाउलर-नॉर्डहाइम (**F-N**) सिद्धांत प्रामुख्याने गुळगुळीत, समतल धातूच्या पृष्ठभागावरून इलेक्ट्रॉनच्या बोगद्यावर लक्ष केंद्रित करतो. प्रतिमा संभाव्य सुधारणांचा समावेश करून, सुधारित **F-N** समीकरण (समीकरण 3) अधिक परिष्कृत प्रतिनिधित्व प्रदान करते, जे उत्सर्जित इलेक्ट्रॉन आणि त्यांच्या पृष्ठभागाच्या संभाव्यतेमधील परस्परसंवादासाठी जबाबदार आहे म्हणजेच प्रतिमा संभाव्यता.

$$J = a\phi^{-1}P_{f}E^{2}\exp\left(-\frac{b\phi^{3/2}}{E}\right) \quad \text{-----(4)}$$

जिथे **Pf** हा पूर्व-घटक आहे आणि तो खालील प्रमाणे दिला जातो

$$J = \frac{4\phi^{3/2}\mu^{1/2}}{(\mu+\phi)}, \quad \text{-----(5)}$$

जिथे, μ - फर्मी ऊर्जा आणि φ - वर्क फंक्शन. **Pf** चे मूल्य अंदाजे एकतेच्या क्रमाचे आहे **(Pf ~ 1).**

$$J = a\phi^{-1}E^{2}\exp\left(-\frac{b\phi^{3/2}}{E}\right), \quad \text{-----(6)}$$

या स्थिरांकांची मूल्ये अशी दिली आहेत: **(a = १.५४ x १०-६ A eV V-2, b = ६.८३ V-3/2 V nm-1).** *E* हे स्थानिक विद्युत क्षेत्र म्हणून पृष्ठभाग क्षेत्र म्हणून मोजले जाते.

डायोड भूमितीमध्ये सपाट कॅथोड पृष्ठभागावर जमा झालेल्या नॅनोपार्टिकल्ससाठी, कॅथोड आणि एनोडमधील लागू केलेले किंवा मॅक्रोस्कोपिक विद्युत क्षेत्र, जे अंतर *(d)* ने वेगळे केले जाते आणि ज्यामध्ये विभवांतर *(V)* असते. तथापि, नॅनोपार्टिकलच्या पृष्ठभागावरील स्थानिक विद्युत क्षेत्र *(E)* β च्या घटकाने *E* पेक्षा जास्त असू शकते, ज्यामुळे क्षेत्रीय परिणाम लक्षणीयरीत्या वाढतात.

$$E = \beta E, \quad \text{-----(7)}$$

जिथे, β - फील्ड एन्हांसमेंट फॅक्टर.

घटक *(β/d)* हा स्थानिक क्षेत्र रूपांतरण घटकाचा व्होल्टेज आहे. **F-N** समीकरण (समीकरण ६) असे पुन्हा लिहिले जाऊ शकते:

$$J = a\phi^{-1}\beta^{2}E^{2}\exp\left(-\frac{b\phi^{3/2}}{\beta E}\right), \quad \text{-----(8)}$$

$$\vec{I} = \vec{S}\times\vec{J} \quad \text{-----(9)}$$

जिथे, I - उत्सर्जन प्रवाह A मध्ये मोजला जातो आणि तो उत्सर्जित पृष्ठभागाचे क्षेत्रफळ आहे आणि β - क्षेत्र वर्धक घटक. याला उत्सर्जक भूमिती असेही म्हणतात. वरील पर्यायांचा वापर करून **F-N** समीकरण आणखी सुधारित केले जाऊ शकते:

$$I = 1.54 \text{ x } 10^{-6} \frac{\beta^2 E^2 S}{t^2(y)\phi} \exp\left(\frac{\left(-6.83 \text{ x} 10^7 \ \phi^{3/2}\right)}{\beta V} \frac{1}{\phi} \left(e^3 E\right)^{1/2} \right),$$

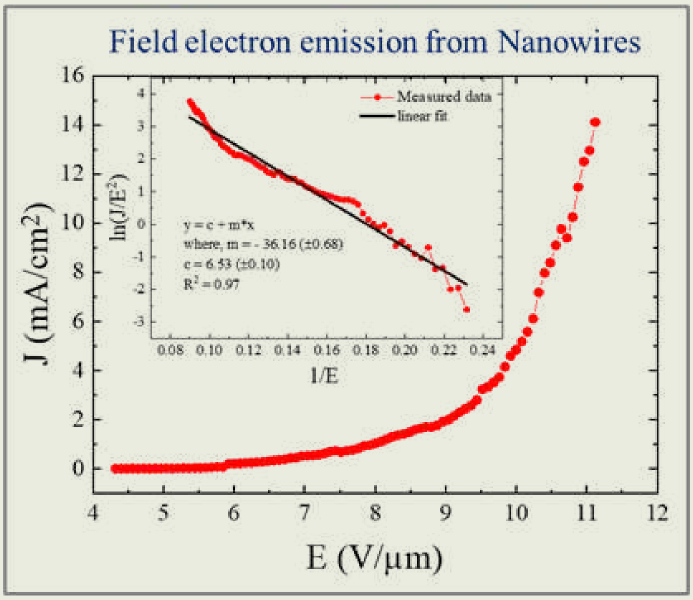
-----(10)

F-N प्लॉट: ln*(I/V^2)* विरुद्ध *(1/V)* चा आलेख F-N प्लॉट असे म्हणतात आणि धातूंसाठी तो सरळ रेषेत असतो. आलेख **(m)** चा उतार जवळजवळ स्थिर असतो. **φ, β** आणि **A** हे **V** पासून स्वतंत्र असल्याने आणि जर आपण प्रतिमा क्षमता दुर्लक्षित केली तर, **g(y) ~ 1** म्हणून परिभाषित केलेले कार्य, म्हणून उतार **m** हा योग्य, स्थिर आणि सरळ रेषेचा असतो.

जरी, फील्ड इलेक्ट्रॉन उत्सर्जन प्रक्रियेत समाविष्ट असलेल्या विद्युत क्षेत्राचे प्रमाण **१०^६ – १०^७ V/cm** च्या क्रमाने खूप जास्त आहे आणि धातूंचे वर्क फंक्शन अंदाजे **३ – ४ eV** दरम्यान असते. सर्व पदार्थांना फील्ड इलेक्ट्रॉन उत्सर्जन गुणधर्म दाखवणे शक्य होणार नाही. हे केवळ उत्सर्जक पृष्ठभागाच्या भूमितीचा वापर करून साध्य केले जाईल म्हणजेच ते अधिक तीक्ष्ण आहे. म्हणून, असे गुणधर्म दाखवण्यासाठी सर्वोत्तम योग्य भूमिती म्हणजे खूप तीक्ष्ण टोके आणि लांबीने लांब असलेले एक मितीय पदार्थ असतील. हे सूचित करते की, अशा पदार्थांचे पक्ष गुणोत्तर मोठे असले पाहिजे.

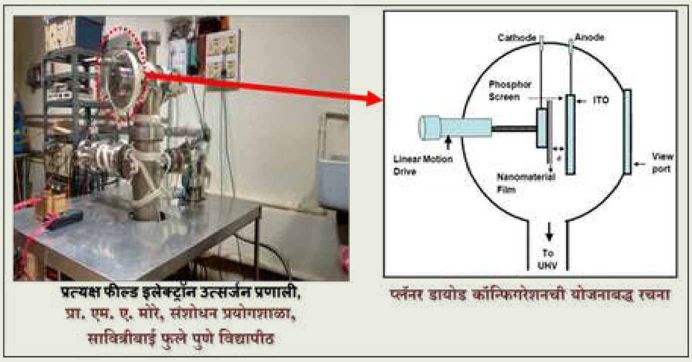
नॅनोवायरमधून फील्ड उत्सर्जन: विविध पदार्थांपासून बनवलेल्या नॅनोवायर ने त्यांच्या विशिष्ट एक मितीय - संरचनांमुळे लक्षणीय रस निर्माण केला आहे, जे क्वांटम कंफाइनमेंट इफेक्ट्स प्रदर्शित करतात. त्यांचे उच्च पृष्ठभाग-ते-आवाज गुणोत्तर विविध अनुप्रयोगांसाठी त्यांची योग्यता वाढवते. विशेष म्हणजे, कमी थ्रेशोल्ड व्होल्टेज आणि किमान ऑपरेटिंग पॉवर असलेले नॅनोवायर फील्ड उत्सर्जन डिस्प्ले तंत्रज्ञानाच्या विकासासाठी मजबूत उमेदवार म्हणून उदयास येत आहेत. उच्च पॅकिंग घनतेसह व्यवस्था केल्यावर, ते फील्ड उत्सर्जन वैशिष्ट्यांमध्ये लक्षणीय सुधारणा करतात. त्यांच्या अक्षीय भूमितीनुसार, नॅनोवायरसारख्या संरचना सपाट सब्सट्रेट्सवर उभ्या वाढवता येतात, ज्यामुळे प्रति युनिट क्षेत्रफळातील तारांची इष्टतम घनता सुनिश्चित होते. अंतिम उद्दिष्ट म्हणजे सुसंगत पैलू गुणोत्तर (लांबी-ते-त्रिज्या) असलेले नॅनोवायरचे सुव्यवस्थित अ ॅरे विकसित करणे, जे सामान्यत: तांबे ग्रिड किंवा प्लेट्स सारख्या स्वयं-शाश्वत सब्सट्रेट्सवर वाढीद्वारे प्राप्त केले जाते. त्यानंतर अशा पृष्ठभागावर उगवलेल्या नॅनोवायरवर त्यांच्या कामगिरीचे मूल्यांकन करण्यासाठी फील्ड उत्सर्जन विश्लेषण केले जाते.

फील्ड इलेक्ट्रॉन उत्सर्जनाची मूलभूत पद्धत: नॅनोस्ट्रक्चर्ड मटेरियल सामान्यतः सब्सट्रेटवर, स्वयं-शाश्वत वाढीवर उगवले जातात, सपाट सब्सट्रेटवर जमा केले जातात किंवा लेपित केले जातात, किंवा सुमारे १ सेमी^2 आकाराच्या कंडक्टिंग कार्बन टेपवर पावडर चिकटवली जाते, ज्यामुळे ब्रॉड-एरिया इलेक्ट्रॉन उत्सर्जक तयार होतो. सब्सट्रेट विद्युत वाहक किंवा अर्धवाहक म्हणून काम करते आणि डिपॉझिशन पद्धतीची निवड सामग्रीच्या गुणधर्मांवर अवलंबून असते. संशोधकांनी रासायनिक वाष्प निक्षेपण, आर्क प्लाझ्मा निक्षेपण, स्पंदित लेसर निक्षेपण, इलेक्ट्रोडपोझिशन, इलेक्ट्रोकेमिकल निक्षेपण आणि स्पिन कोटिंग यासह विविध तंत्रे वापरली आहेत. उपलब्ध सब्सट्रेट्समध्ये, सिलिकॉन सर्वात जास्त वापरला जातो कारण तो इलेक्ट्रॉनिक उपकरण एकत्रीकरणाशी सुसंगत असतो, ज्यामुळे कॅथोड तयार होतो. एनोडमध्ये इंडियम टिन ऑक्साईड-लेपित कंडक्टिंग ग्लास प्लेट असते, ज्यामध्ये फॉस्फर कोटिंग असू शकते. एनोड-कॅथोड पृथक्करण सामान्यतः काही मायक्रॉनपासून काही मिलीमीटरपर्यंत असते, क्वार्ट्ज किंवा अ ॅल्युमिना स्पेसरद्वारे राखले जाते, ज्यामुळे डायोड कॉन्फिगरेशन तयार होते जे खालील आकृतीमध्ये दर्शविले आहे. प्रयोगशाळेत एकत्रित केलेल्या फील्ड उत्सर्जन प्रणालीची प्रत्यक्ष प्रतिमा घेतली जाते आणि मोजमाप केले जातात. अ ॅनोड आणि कॅथोड असलेले होल्डर अल्ट्रा-हाय व्हॅक्यूम चेंबरमध्ये ठेवले जाते, जे अंदाजे **१०^७** ते **१०^८** **mbar** च्या दाबावर रिकामे केले जाते. एक स्थिर **DC** पॉवर सप्लाय इलेक्ट्रोड्सवर उच्च व्होल्टेज **(० - १० kV)** लागू करतो, तर इलेक्ट्रोमीटर अ ॅम्प्लिफायर **१०^९** ते **१०^६** A च्या श्रेणीत विद्युत प्रवाह मोजतो. विविध लागू केलेल्या व्होल्टेजमध्ये व्होल्टेज-करंट वैशिष्ट्यांचे मूल्यांकन केले जाते आणि पूर्वनिर्धारित अंतराने फील्ड उत्सर्जन प्रवाहाचे निरीक्षण करून विद्युत स्थिरता अभ्यास केले जातात. परिणामी फील्ड उत्सर्जन नमुना अ ॅनोड स्क्रीनवर प्रदर्शित केला जातो आणि आवश्यकतेनुसार रेकॉर्ड केला जातो.



आकृती ३: उपयोजित क्षेत्र लागू केल्यावर नॅनोमतेरीयल्स

(नॅनोवायर) पासून फील्ड इलेक्ट्रॉन विद्युतधारा घनता उत्सर्जन. (आकृती अंतर्गत: एफ-एन प्लॉट)



आकृती ४: UHV चेंबरमधील प्लॅनर डायोड कॉन्फिगरेशन व्यवस्थेची योजनाबद्ध आणि प्रत्यक्ष फील्ड इलेक्ट्रॉन उत्सर्जन सिस्टम असेंब्ली.

विशेष आभार: प्रा. महेंद्र अ. मोरे, ईमेरिटस प्राध्यापक, फील्ड उत्सर्जन संशोधन प्रयोगशाळा, भौतिकशास्त्र विभाग, सावित्रीबाई फुले पुणे विद्यापीठ, पुणे.

Prof. S. S. Gaikwad serves as an Assistant Professor in the Department of Physics at MES's Nowrosjee Wadia College. He has successfully qualified both the SET and JEST examinations, demonstrating his strong academic foundation. Prof. Gaikwad brings over a decade of teaching experience, including a distinguished four-year research tenure at National Dong Hwa University, Taiwan.

He has authored seven research articles in reputed peer-reviewed journals and actively contributes to science communication through a wide array of educational content on YouTube. His research expertise spans energy storage materials, supercapacitors, field emission devices, and metal oxide semiconductors.

Semiconductor Materials: History, Fundamental and Applications

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The advancement of semiconductor physics and technology has transformed modern life, making semiconductors indispensable in fields such as energy, sensing, electronics, biomedical applications, imaging, and water treatment. This chapter provides an overview of semiconductors, covering their definition, characteristics, history, band structure, physics, and classification. It then highlights key applications in energy. Overall, the chapter aims to give a comprehensive yet concise understanding of semiconductor science and its practical applications.

1. Introduction

1.1 Definition, characteristics

The word semiconductor comes from the combination of semi (partial) and conductor (a material that carries electricity). As the name suggests, semiconductors possess electrical properties that fall between those of conductors and insulators, allowing them to conduct current under suitable conditions.

One of their most distinctive features is the temperature dependence of their conductivity. Unlike metals, whose conductivity decreases as temperature rises, semiconductors show the opposite behaviour—their conductivity increases with temperature. Another key property is the tunability of the energy band gap (Eg), which is central to determining the scope of semiconductor applications.

The electrical and physical behavior of semiconductors is strongly influenced by interatomic bonding, structural characteristics, and the presence of defects. Depending on whether they are amorphous, crystalline, or polycrystalline, semiconductors serve in diverse fields such as energy technologies and electronics. Additionally, doping—the intentional introduction of impurities—provides a powerful means to modify conductivity and band gap. This process enables the design and fabrication of a wide range of semiconductor devices that are now integral to modern life.

1.2 History

The history of semiconductors spans more than a century, with early observations dating back to the late 18th century. Alessandro Volta first used the term semiconducting in 1782, and Michael Faraday in 1833 noted the unusual temperature-dependent resistance of silver sulfide. Later, discoveries such as selenium's photoconductivity (Smith, 1873), Braun's observation of rectifying metal–sulfide contacts (1874), and the Hall Effect (1879) laid important groundwork. The term *semiconductor* was formally introduced in 1911, and the first practical devices, such as copper oxide and selenium rectifiers, appeared in the 1920s–30s. A major breakthrough came in 1931 when A. H. Wilson applied quantum mechanics to explain semiconductor behavior, followed by advances in photocells, infrared detectors, and microwave devices through the 1930s–40s.

The invention of the germanium transistor in 1949 and the silicon-based field-effect transistor in the 1950s revolutionized electronics, establishing silicon as the cornerstone of microelectronics. Later, III–V semiconductors like GaAs further expanded applications in optoelectronics. Today, integrated circuits built from semiconductors contain billions of components and underpin nearly every modern technology, while ongoing research seeks new materials with enhanced properties for energy, sensing, communication, and computing.

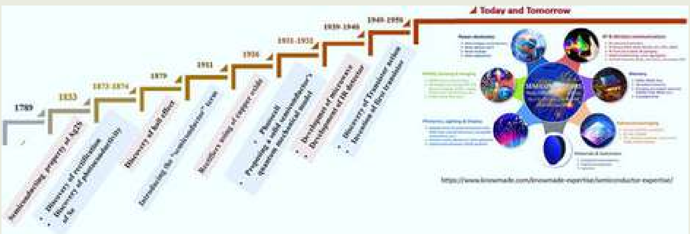

Figure 1. A schematic brief of the history of semiconductors

2. Semiconductor categories

2.1 Chemical composition Classifications

Semiconductors can be classified into three main categories: elemental, compound, and alloy-based materials (Figure 2).

1. **Elemental semiconductors** – The most widely used are silicon (Si) and germanium (Ge).
2. **Compound semiconductors** – These are formed from elements of different groups in the periodic table, such as II–VI, III–V, III–VI, IV–IV, and IV–VI. Common examples include GaP, GaAs, GaN, and SiC.

- **Alloy semiconductors** – These are engineered by combining two or more semiconductors and are further divided into:
  - **Binary alloys** (e.g., $Si_{1-x}Ge_x$),
  - **Ternary alloys** (e.g., $Al_xGa_{1-x}As$, $Al_xGa_{1-x}N$),
  - **Quaternary alloys** (e.g., $Al_xGa_{1-x}As_ySb_{1-y}$, $Ga_xIn_{1-x}As_yP_{1-y}$).

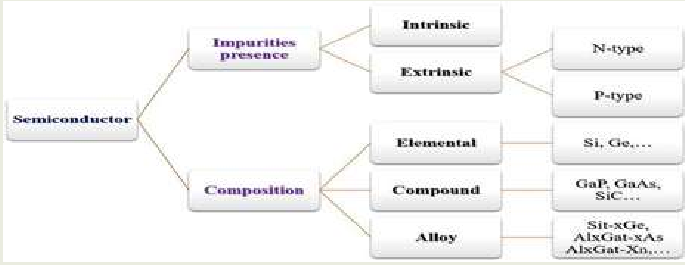

Figure 2. Semiconductor's categories.

2.2 Intrinsic and extrinsic

Semiconductors are generally divided into intrinsic and extrinsic types (Figure 2). Intrinsic semiconductors are pure, undoped materials whose conductivity arises mainly from thermal excitation or crystal defects, producing equal numbers of electrons and holes. The carrier concentration is determined solely by the material's properties. In contrast, extrinsic semiconductors are created by doping intrinsic materials with small amounts of impurities to enhance conductivity (Figure 3). Depending on the dopant, they are classified as n-type (using group V elements like P, As, or Sb to increase electron concentration) or p-type (using group III elements such as B, Al, or Ga to increase hole concentration).

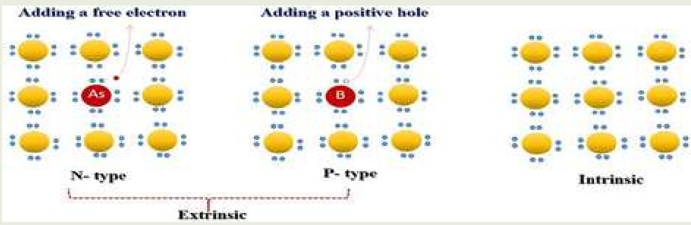

Figure 3- Intrinsic and extrinsic Semiconductors.

3. Key Characteristics of Semiconductors

3.1 Semiconductor Characteristics

Crystalline solids are the most common semiconductors, amorphous and even liquid forms also exist. Their electrical behavior depends strongly on composition, structure, and size. Generally, semiconductors exhibit properties intermediate between conductors and insulators. For reference, metals typically have conductivities between 10^6 and 10^4 $(\Omega\cdot cm)^{-1}$, insulators below 10^{-10} $(\Omega\cdot cm)^{-1}$, while semiconductors span a wide range from about 10^6 to 10^{-10} $(\Omega\cdot cm)^{-1}$.

Table 1: Summery of key characteristics of Semiconductors.

Conductivity	Moderate
Resistivity	Moderate
Forbidden gap	Small forbidden gap $\Delta E \leq$ 3.2 eV (at T = 0 K)
Temperature Coefficient	Negative
Conduction	Very small number of electrons for conduction
Conductivity value	10−7 mho/m to 10−13 mho/m, distinguish conductors from insulators
Resistivity value	10−5 Ω-m to 105Ω-m, classifying them as conductors or insulators
Current flow	Due to holes and unbound electrons
Number of carriers at normal temperature	Low
Zero Kelvin behavior	Acts like an insulator
Formation	Formed by covalent bonding
Valence electrons	The outermost shell contains a total of four valence electrons

3.2 Band theory

The development of Bloch's theory and Brillouin's concept of electrons in periodic lattices introduced the idea of forbidden energy gaps, leading to the foundation of band theory of solids. According to this model, when atoms come together to form a crystal, their atomic orbitals overlap, giving rise to continuous ranges of allowed energy states called bands. The highest occupied band at normal temperatures is the valence band (VB), while the next higher band, separated by an energy gap (1 eV in semiconductors), is the conduction band (CB). Electrons in the CB and holes in the VB are responsible for charge transport.

Band theory explains the distinction between conductors, semiconductors, and insulators. Following Pauli's exclusion principle, each atomic orbital splits into multiple molecular orbitals when atoms combine. For a solid containing $\sim 10^{23}$ atoms, these orbitals generate an enormous number of closely spaced energy states. The energy levels are so dense that they merge into continuous energy bands. For example, an s-orbital band can hold 2n electrons, while a p-orbital band can accommodate 6n electrons (where n is the number of atoms). Thus, band formation transforms discrete atomic levels into continuous electronic states, as illustrated in Figure 4.

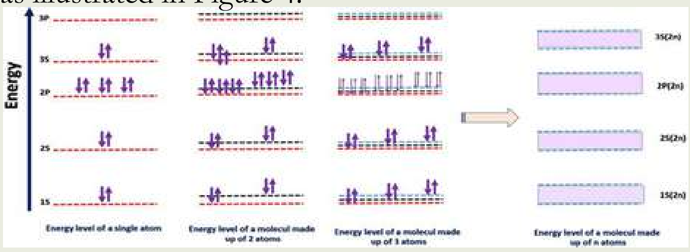

Figure 4: Energy band evolution in a material containing n atoms

Valence electrons occupy the outermost shell of an atom and collectively form the valence band, which contains the highest filled energy states. Because their bond with the nucleus is relatively weak, some of these electrons can gain enough energy to escape into the conduction band, becoming free electrons that carry current. The region separating the valence and conduction bands is the band gap (forbidden gap), which contains no allowed energy states. Materials are classified based on this gap: if $\Delta E \leq 3.2$ eV (at 0 K), the material behaves as a semiconductor, while $\Delta E >$ 3.2 eV corresponds to an insulator. The 3.2 eV threshold aligns with the maximum photon energy available from sunlight.

In addition, materials with a slight overlap between the conduction and valence bands are known as semimetals. These possess both electrons and holes as charge carriers, though in smaller numbers compared to true metals. Consequently, their electrical properties fall between those of metals and semiconductors. Figure 5 illustrates the band structures of semiconductors, insulators, metals, and semimetals.

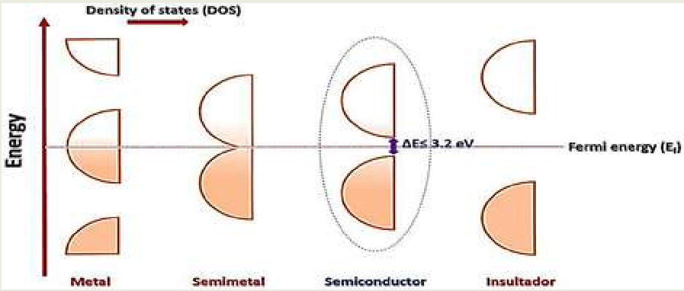

Figure 5. Band structure of Metal, Semiconductor and Insulator

3.2.1 Doping effect on band structure

Extrinsic semiconductors are formed by doping a pure crystal lattice with small amounts of impurity atoms, which introduce additional charge carriers with distinct energy states. In n-type semiconductors, donor atoms contribute extra electrons that occupy energy levels just below the conduction band. Because these donor levels lie very close to the conduction band, even small amounts of thermal energy can excite electrons into it, enhancing conductivity. In contrast, p-type semiconductors contain acceptor atoms that create vacant states (holes) just above the valence band. These acceptor levels make it easy for electrons to transition from the valence band, leaving behind mobile holes that conduct current. Figure 6 illustrates how doping alters the band structure and energy gap by introducing donor or acceptor levels. Band engineering is an essential approach for tailoring the physical, electrical, and optical properties of semiconductors to optimize their performance in various applications. In recent years, extensive research has focused on modifying band structures to enhance and control the functional characteristics of semiconductor materials.

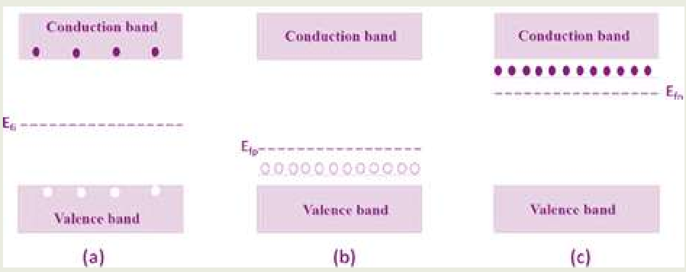

Figure 6. Energy bands of (a) intrinsic semiconductor, (b) extrinsic p-type semiconductor, and (c) extrinsic n-type semiconductor

4. Applications of Semiconductors

Semiconductors are vital materials whose tunable properties make them indispensable across diverse fields. They have transformed modern life by enabling compact, efficient, and cost-effective technologies such as computers, mobile phones, LED displays, and other electronic devices. Broadly, their applications span energy, electronics, sensing, biomedical devices, antibacterial and anticancer treatments, quantum technologies, and water purification.

In the energy sector, semiconductor applications can be grouped into conversion and storage. For energy conversion, materials such as Si, CdTe, and GaAs are widely used in photovoltaic cells to harvest solar energy. Advances in thin-film semiconductors and perovskites are further enhancing efficiency and lowering costs, driving progress in sustainable power generation. For energy storage, semiconductors are integral to lithium-ion batteries, where they improve capacity and cycle life. Emerging research on silicon-based anodes and other semiconductor materials is paving the way for next-generation batteries with greater energy density and durability.

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Electrochemical Sensors

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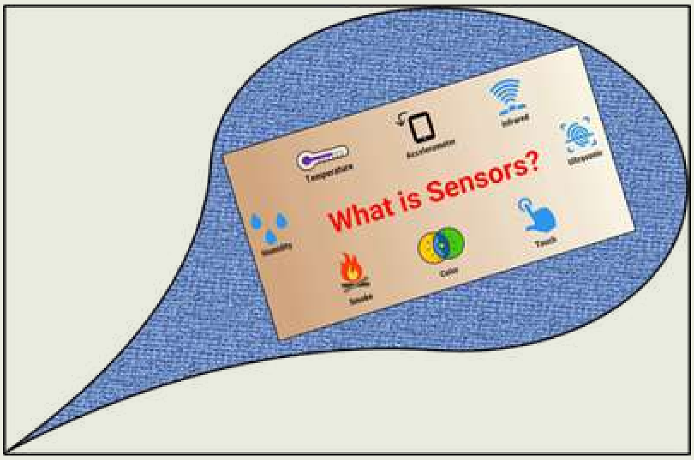
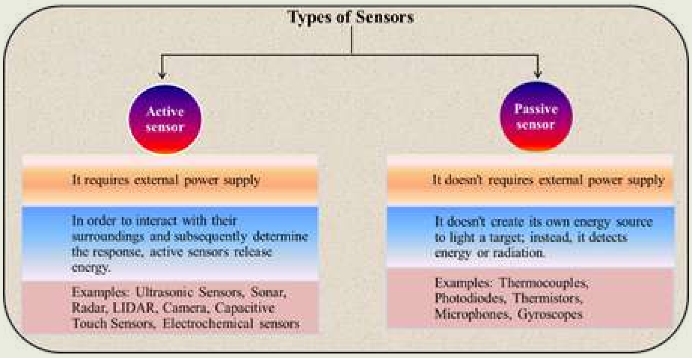


A **sensor** is a device that detects the change in the environment and responds to some output on the other system. A sensor converts a physical phenomenon into a measurable analog voltage (or sometimes a digital signal) converted into a human-readable display or transmitted for reading or further processing.

Types of sensors:



Electrochemical sensor

History behind the electrochemical sensor-

Max Cremer created the first pH sensor in 1906 as a result of ***Faraday*** and others' basic electrolysis research, which marked the beginning of the history of electrochemical sensors. The first glucose biosensor was created in the 1970s, whereas Leland C. Clark created the oxygen sensor in the 1950s. Ion-selective electrodes were developed in the 1940s, micro fabrication was developed in the 1990s, and Nano sensors have recently gained popularity.

Basically, electrochemical sensors convert electrochemical reactions into quantifiable electrical signals, such voltage or current, in order to detect analytes. The analyte is oxidized or reduced at the sensing electrode, and they usually include a working electrode (*where the electrochemical reaction with the analyte occurs*), a reference electrode (*provides a stable and constant electrical potential*), and a counter electrode (*completes the circuit and ensures the flow of current*) submerged in an electrolyte (*A solution that contains ions and facilitates the flow of charge between the electrodes*). Depending on how they measure the signal, these sensors are divided into three categories: conductometric (conductivity), amperometric (current), and potentiometric (voltage). Detecting gases such as pollutants, identifying biomolecules for the diagnosis of diseases, and monitoring different ions and metals in industrial and medical contexts are examples of common applications.

Electrochemical sensors, which transform a chemical or biological response into a quantifiable electrical signal, are employed in a wide range of sectors to detect chemical compounds. Food safety for contaminant detection, industrial safety for detecting harmful gases like carbon monoxide, environmental monitoring for pollutants like metal ions and acid gasses, and healthcare diagnostics for blood glucose monitoring are some of the main applications. Additionally, they can be found in consumer electronics, wearable health monitoring gadgets, and defense systems for combatants.

How does electrochemical sensor woks?

Electrochemical sensors detect the presence or concentration of a chemical substance (analyte) by measuring changes in electrical properties (such as current, voltage, or conductivity) caused by a chemical reaction at an electrode surface. It acts as a **bridge between chemistry and electronics,** converting a **chemical event** into an **electrical signal.** In this, the **electrons are transferred** during chemical reactions. The sensor captures this **electron movement** as an **electrical signal** that is proportional to the amount (concentration) of the target analyte. By considering the following steps electrochemical sensor works.

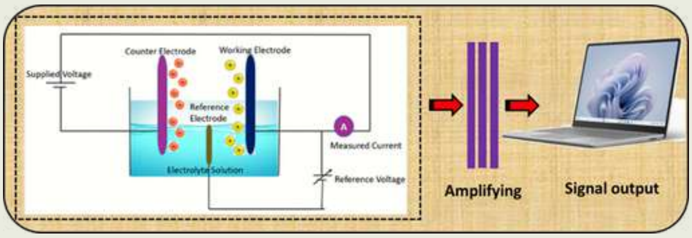


Fig: Cell assembly of electrochemical sensor

1. Redox Reaction: The analyte interacts with the surface of the working electrode, undergoing either Oxidation (loss of electrons), or Reduction (gain of electrons), this reaction occurs in an electrochemical cell, which typically includes: Working Electrode, Reference Electrode and Counter Electrode. However, the electrochemical cell is usually immersed in an electrolyte solution that provides the plenty of ions.

2. Electron Transfer and Signal Generation: When a redox reaction occurs at the electrode due to the releasing or accepting the electrons creates an electrical current or voltage (what is measuring). The magnitude of this signal depends on how much analyte is present.

3. Signal Processing: The received electrical signal (current, voltage, or resistance) is get amplified, filtered or can be converted to a digital format and processing and displaying as a concentration value (e.g., mg/L, ppm). This allows the user can easily read and interpret the data.

Recent developments and nanomaterials in electrochemical sensor

The following are the types of nanomaterials used in the application of electrochemical sensors

- Carbon-Based Nanomaterials: Carbon Nanotubes, Graphene, Fullerenes, Carbon Dots, Nanohorns
- Magnetic Nanoparticles (MNPs)
- Single-Walled Carbon Nanohorns (SWNHs)
- Graphene Quantum Dots (GQDs)
- MXenes (2D Carbides/Nitrides)
- Conductive Metal–Organic Frameworks (MOFs)

Recent developments

1. Edible, Eco-Friendly Nano-Conductive Paste (FN-CoP)

Researchers at BITS Pilani, Hyderabad, have introduced a **food-based, biodegradable conductive paste (FN-CoP)**—composed of activated carbon (~56 nm), gelatin, and oral rehydration solution—that's printable and highly biocompatible. Aimed at wearable, ingestible, and edible biosensors, it supports applications like breath analysis and biomarker detection. Production costs are remarkably low at ₹129 per 100 g, making it both sustainable and scalable. (Resources: The Times of India)

2. Digital Integration & Wearable Platforms

Voltammetric sensors enhanced with nanomaterials are increasingly being integrated into **portable and wearable formats.** These systems leverage wireless connectivity (e.g., Bluetooth, Wi-Fi), microcontrollers, and even implantable designs to deliver real-time biomarker monitoring [e.g., glucose, lactate, and uric acid], ideal for remote or resource-limited settings.

3. AI & Machine Learning for Signal Interpretation

AI and ML techniques are being used to process complex electrochemical data. Neural networks and other models aid in pattern recognition, anomaly detection, adaptive calibration, and noise filtering—greatly enhancing analytical accuracy in dynamics.

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Emerging Trends in Semiconductor-Based Photosensors: A Study on $Zn_{0.8}Mg_{0.2}S$ Nanorod Films

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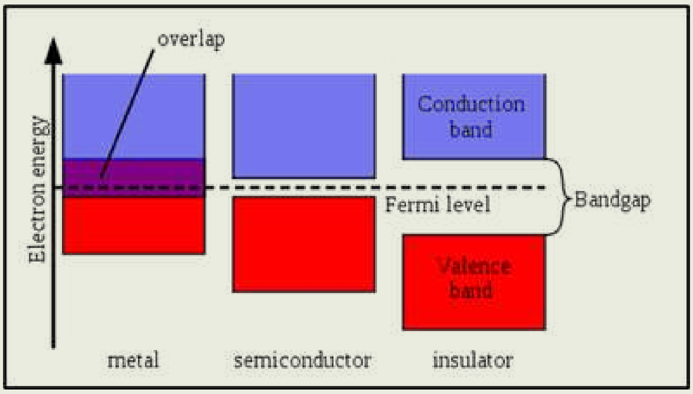
Introduction

The pursuit of efficient, eco-friendly photosensors has led to significant innovations in semiconductor nanostructures. This article explores the synthesis and performance of $Zn_{0.8}Mg_{0.2}S$ nanorod thin films fabricated via chemical bath deposition. These films exhibit promising optoelectronic characteristics, including high photosensitivity and tunable bandgap, positioning them as viable alternatives to cadmium-based sensors. The study underscores the role of morphology, crystallinity, and doping in enhancing visible light detection.

Photosensors are pivotal in modern technology, enabling applications from biomedical imaging to environmental monitoring. The integration of semiconductor nanostructures—especially one-dimensional forms like nanorods—has transformed device performance by improving charge mobility and light absorption. Among II-VI semiconductors, ZnS and its magnesium-doped variants offer a cadmium-free solution with adjustable optical properties and structural versatility.

Understanding Semiconductors

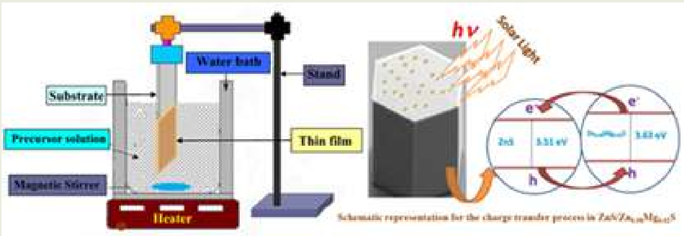
Semiconductors like silicon exhibit unique behaviour due to their band structure. The small energy gap between the valence and conduction bands allows electrons to move under specific conditions. Doping—adding impurities—modifies their conductivity:



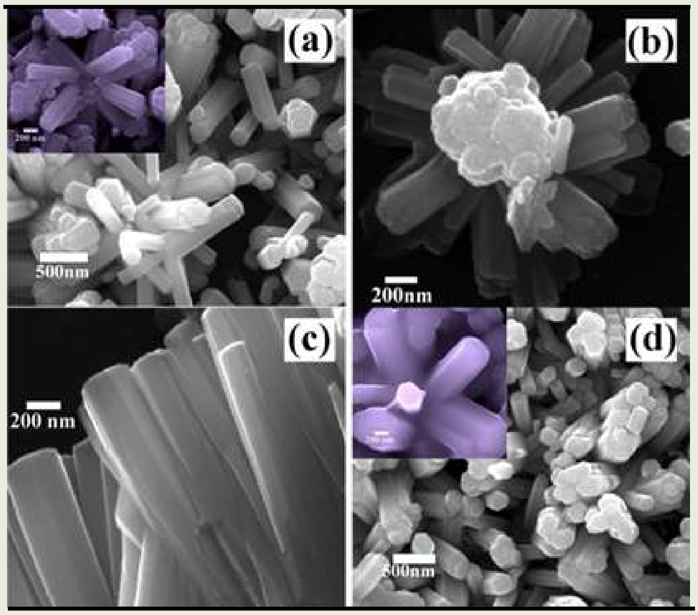
N-type: Extra electrons (e.g., phosphorus in silicon)
P-type: Positive holes (e.g., boron in silicon)
The PN junction, formed by combining n-type and p-type materials, is the foundation of diodes, transistors, and solar cells.

Experimental Methodology

Thin films of $Zn_{0.8}Mg_{0.2}S$ were grown on glass substrates using a low-temperature chemical bath deposition technique. The precursor solution comprised zinc sulfate, magnesium acetate, and thiourea, with triethanolamine serving as a complexing agent. The pH was stabilized at ~11 using ammonia, and the deposition was carried out at 80°C for one hour. Post-deposition annealing at 100°C enhanced film quality and crystallinity.

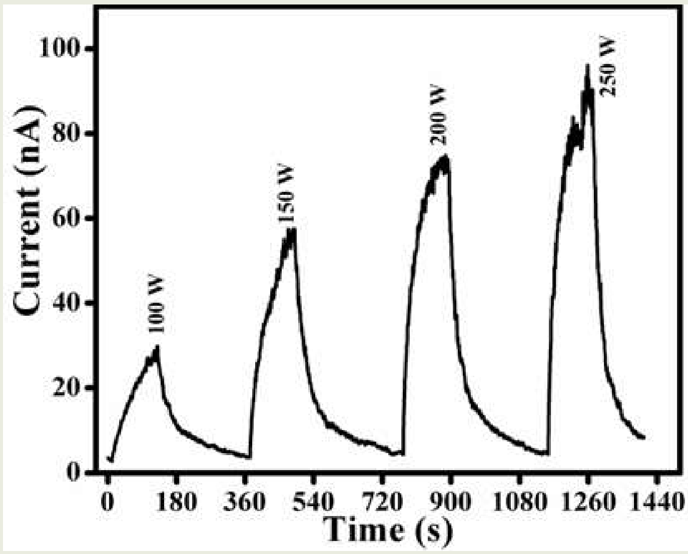


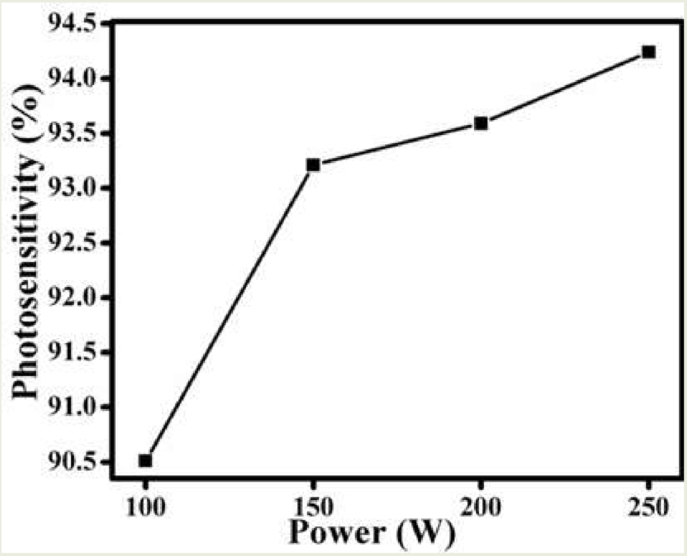
Characterization and Analysis



X-ray diffraction revealed a hybrid crystal structure combining wurtzite and zinc blende phases. The dominant (002) orientation was corroborated by FE-SEM, which showed vertically aligned nanorods. TEM analysis indicated rod diameters between 136–149 nm and lengths up to 534 nm. SAED confirmed the crystalline nature, while EDAX validated the elemental composition, with Zn, Mg, and S present in expected ratios. Raman spectroscopy identified vibrational modes linked to ZnS and MgS, with shifts suggesting improved crystallinity post-annealing. Photoluminescence spectra displayed UV emissions at 373 nm (as-deposited) and 348 nm (annealed), corresponding to bandgaps of 3.32 eV and 3.56 eV. The observed blue shift was attributed to magnesium incorporation and carrier concentration effects. UV-visible absorption spectra supported these findings, showing enhanced absorbance and a sharper absorption edge in annealed samples.

Photodetection Performance



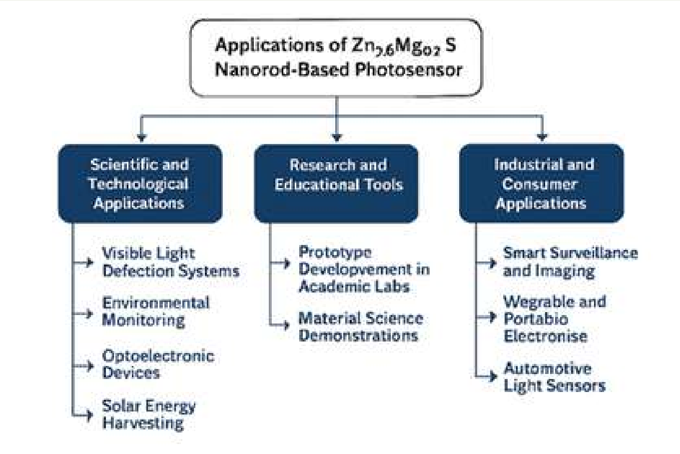


Under simulated solar illumination, the annealed films demonstrated a marked increase in photocurrent. At 5 V bias and 100 W/cm² intensity, the photosensitivity reached 90.51%. Response and recovery times were recorded at ~93 s and ~140 s, respectively. The nanorod architecture facilitated efficient light harvesting and minimized recombination losses, contributing to rapid and stable switching behaviour.

Comparative Perspective

Compared to conventional nanostructured photosensors—such as ZnO nanorods and SnO_2 nanowires—the $Zn_{0.8}Mg_{0.2}S$ system offers competitive performance with the added benefit of cadmium-free composition. The chemical bath deposition method stands out for its simplicity, low cost, and scalability, making it suitable for large-area device fabrication without compromising material quality.

Applications of Photosensor



Conclusion

This study highlights the potential of $Zn_{0.8}Mg_{0.2}S$ nanorod thin films as high-performance photosensors for visible light applications. Their tunable bandgap, robust morphology, and strong photoresponse make them ideal candidates for next-generation optoelectronic devices. The use of a straightforward synthesis route further enhances their appeal for sustainable and scalable manufacturing.

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Do You Know ?

Facts about the Photosensors:

- Salvaged from CD-ROM Drives Many early consumer electronics, like CD-ROM drives, contain compact photodetectors often clusters of photodiodes that can be repurposed for DIY optical experiments.
- Photosensors aren't limited to the photoelectric effect. Some operate via photochemical reactions, thermal effects, polarization changes, or even weak interaction phenomena like photon drag and pressure shifts in Golay cells.
- Origins in Astronomy and Nuclear Physics Photomultiplier tubes, invented in the 1930s, were pivotal in detecting faint light signals in nuclear and astrophysical research, long before their use in medical imaging or particle physics.
- Retroreflective photoelectric sensors can detect transparent objects like glass or plastic film by measuring subtle changes in reflected light, making them ideal for packaging and automation.
- Thru-beam sensors are surprisingly resilient in dusty or dirty industrial settings. Their long-range detection and tolerance to contamination make them indispensable in harsh environments.
- FER and STM Integration Advanced photosensors are now integrated with techniques like Field Emission Resonance (FER) and Scanning Tunneling Microscopy (STM), enabling atomic-scale light detection and surface mapping especially in nanoscience and quantum materials.

Semiconductor Physics: The Living Edge of Innovation

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From the heart of your smartphone to the control systems of a Mars rover, semiconductors quietly power nearly every aspect of modern life. But the most exciting changes today are not just about making them smaller or faster — they are about making them smarter, more adaptable, more resilient, and deeply mindful of the environment. The new wave of semiconductor physics is beginning to blur the line between machines and living things, giving rise to devices that can think, feel, heal, and care — living in balance with the world around them.

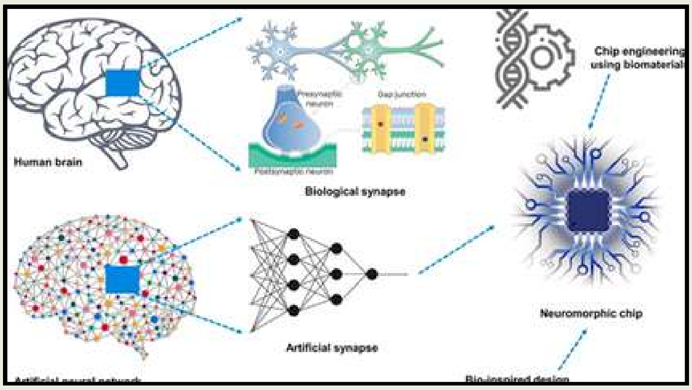
From Circuits to Minds

Imagine a chip that doesn't just calculate numbers, but understands patterns, learns from experience, and adapts to new situations — much like the human brain. These are neuromorphic chips. Instead of separating memory and processing into different regions, they merge both, just like neurons and synapses in our nervous system.

Some neuromorphic chips use memristors — special components that can "remember" past electrical states — to mimic the way biological brains store and adapt information. Built on flexible materials, they can be woven into wearable devices, embedded into medical patches, or installed in agile robots. By processing sensory inputs — vision, sound, or touch — directly at the point of collection, they avoid the delays and power costs of sending data to distant servers. This not only makes them faster but also vastly more energy-efficient, bringing artificial intelligence closer to human-like efficiency.

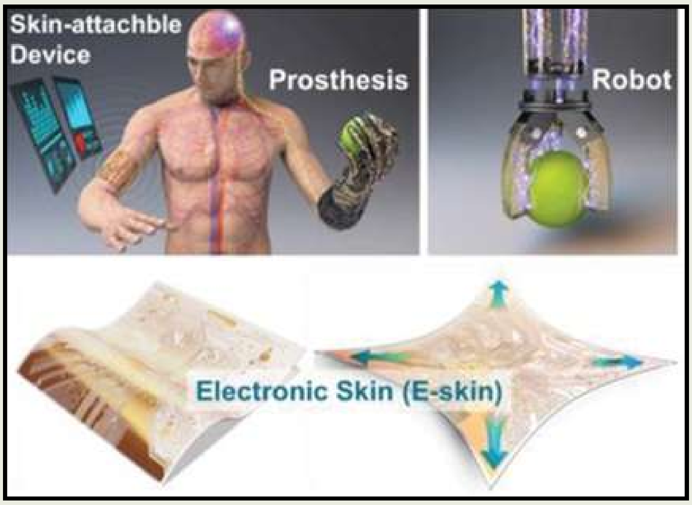
Machines That Feel

Just as the brain processes touch through the skin, scientists are creating semiconductors that act like human skin itself. Traditional silicon is rigid and brittle, but these new materials are soft, bendable, and stretchable, containing microscopic sensors that can



detect pressure, temperature, and even texture.

Robots equipped with this "electronic skin" could handle delicate objects without crushing them, detect subtle environmental changes, and interact with humans more safely. Prosthetic limbs could restore a sense of touch to their users, allowing them to feel the warmth of a cup of tea or the texture of fabric. When paired with neuromorphic chips, these skins don't just sense — they interpret — just like our nervous system.

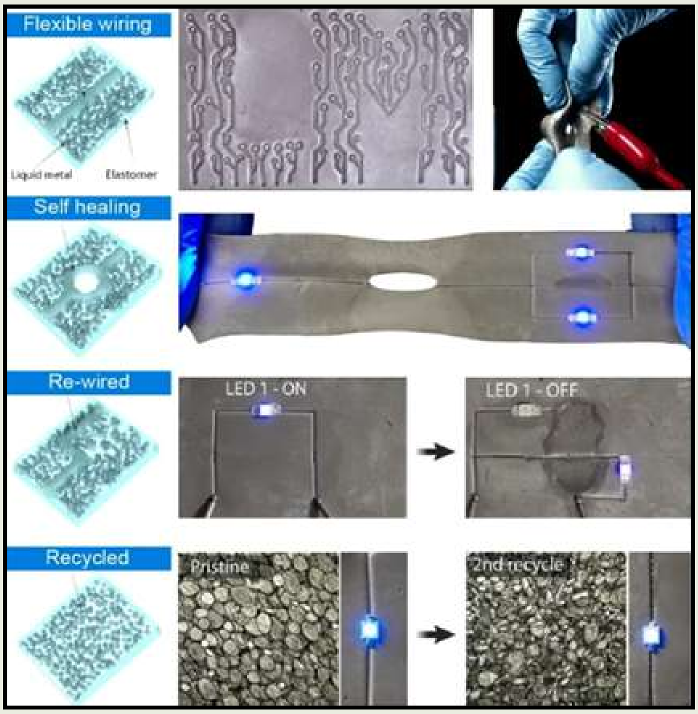


Electronics That Heal

Even the most advanced machines can break. Traditionally, a damaged circuit means costly repairs or total replacement. But scientists are developing self-healing semiconductors that can repair themselves automatically.

Some designs use microcapsules filled with liquid metals or conductive ink. When cracks form, the capsules break and release their contents, restoring the circuit instantly. Others rely on materials with reversible chemical bonds that re-form when exposed to heat or light. These innovations are especially crucial for electronics in places humans can't easily reach — satellites in orbit, deep-ocean sensors, or implanted medical devices.

Picture a spacecraft surviving a micrometeorite strike by patching its own electrical wounds, or a health-monitoring patch silently healing itself overnight without interrupting its work.



Technology That Cares

As semiconductors become more capable, they must also become more responsible. Chip production consumes vast amounts of energy and water, and uses rare or toxic materials. At the same time, e-waste has become a mounting global problem.

To address this, researchers are developing eco-friendly semiconductors made from renewable, recyclable, or biodegradable materials.

Or a smartphone chip that can be safely recycled into new devices instead of ending up in a landfill. New fabrication techniques are also reducing the use of harmful chemicals and minimizing waste in production. Imagine a medical patch that monitors your health for a few weeks, then dissolves harmlessly.

Emerging Fusion of Vision and Reality

What's most exciting is when all these ideas come together. Imagine a disaster-relief robot with skin-like sensors, powered by a brain-like neuromorphic chip, able to heal its circuits after damage, and made from materials that care for the planet. Or picture a spacecraft exploring distant planets for decades, without any maintenance, while leaving no footprint behind!!!

This is not science fiction — each part of this vision is already being developed in labs around the world. Semiconductor physics is no longer only about moving electrons faster. It's about creating electronics that adapt, survive, and work in harmony with the environment.

The next chapter of semiconductor physics will not just be written in silicon, but in materials and designs that echo the living systems they are inspired by — the ultimate ideal philosophy to create technology so deeply woven into our existence that it is as much a part of life as life itself.

"Eel-ectrifying": Unveiling the Nature's Battery Powerhouse

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Even long before the efforts of the Greek philosopher, Thales of Miletus in 600 BCE on static electricity, or Alessandro Volta's invention of the first-ever electrical battery, or the "War of the Currents" between Nikola Tesla and Thomas Edison, the greatest scientist of all, Mother Nature, was already an expert at generating and utilizing the electricity. Be it in the minute form of neuron firing in a living cell's nervous system or a grand lightning bolt splitting across the sky with raw, blinding power, electricity ventures electrifyingly fast, unseen yet real.

Over centuries, scientists such as Benjamin Franklin proved that lightning was a form of electricity while Michael Faraday revealed magnetism and the nature of electricity, which dance together as one, to exist mutually. Fast forward, the electricity lit up our homes, powered machines, and connected our world as well as the universe. While humans were just beginning to harness this force, nature – chuckling silently – had already evolved smart organisms that could generate, store, and release electricity, though not with wires and metals, but with living tissues.

In the mysterious and murky waters of the Amazon, an intelligent creature glides silently. She is Electrophorus electricus, known to most as the electric eel - and nature's own electricity generator. She doesn't just sense the electricity; she creates it and is not afraid to use it for hunting as well as defence.

Though called an "eel," Electrophorus is actually a type of knifefish, more closely related to the catfish than to true eels. Her body, long and muscular, is a marvel of natural engineering and hidden inside it lies an incredible biological mechanism: a natural electric organ system capable of generating an impressive voltage from 600 to 800 V and around 1 A of current in short bursts, taking the generated electric power around 660 to 880 W for a few milliseconds.

Figure 1: The Electric Eel (Electrophorus electricus)

Evolution of a shockwave:

The electric eel's power did not appear overnight, but evolved cell by cell, from something surprisingly ordinary: muscle tissue. In the eel's ancestors, certain muscle cells gradually lost their ability to contract, and instead specialised in one thing: ***moving ions,*** giving rise to electrocytes that are the cells capable of generating electric discharges.

These electrocytes are stacked ***in series*** within the electric organ, amplifying the voltage to deliver powerful shocks. [1]

But Electrophorus isn't the only one blessed by nature. Across the world, several other fish, like African Knifefish *(Gymnarchus niloticus)* and Electric Catfish *(Malapterurus electricus)*, developed similar electric organs. This is an example of ***convergent evolution:*** when different species, facing similar challenges, evolve the same solution in parallel but unknown to each other.

Genetic studies have revealed that these electric organs, despite arising independently, share common genetic pathways [1]. For instance, research has shown that the same gene, Scn4a, plays a crucial role in the development of electric organs across different species, highlighting the parallel evolutionary solutions to similar challenges posed by nature. [2]

Biology of Electricity:

Imagine stacking thousands of tiny coins, each holding a small electric voltage. One coin does nothing, but a thousand wired together? That's power, and that's how the electric eel works.

As shown in Fig. 2, her three electric organs, **the Main organ, Hunter's organ,** and **Sach's organ,** are made of stacks of electrocytes. Together, these organs make up nearly 80% of her body length. Each electrocyte maintains a resting membrane potential of about 85 millivolts, created by the careful separation of sodium and potassium ions across its cell membrane.

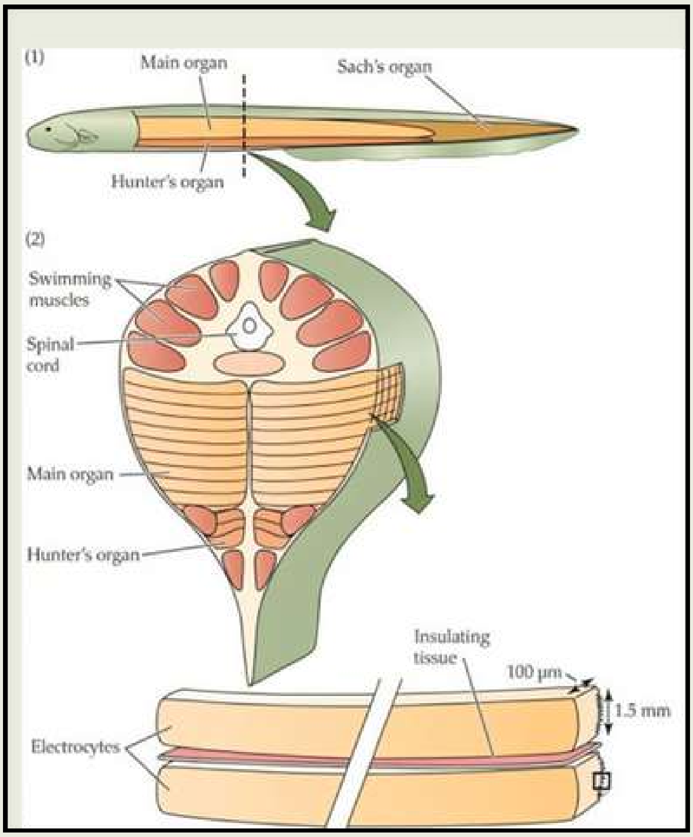

Figure 2: The electrical organ of an eel. It is a special organ made up of modified nerve cells and muscles and is activated by nerve stimulation. *[Image source: AnimalWorld.com.ua – Electrophorus electricus article]*

When an eel decides to generate an electric discharge, her brain sends a rapid signal through the ***spinal cord,*** activating thousands of electrocytes simultaneously. This signal opens ion channels, causing a ***sudden reversal of membrane polarity*** in these cells, and each electrocyte releases a small voltage.

Alone, a single electrocyte's output is tiny. But when stacked in series, much like the cells in a battery, they create a powerful electric pulse. A large eel can produce more than 600 V of voltage, double the voltage of a wall socket.

Electricity with Purpose:

Eel uses generated voltage with precision. She produces two types of electrical discharges, each with a distinct purpose:

1. Low-Voltage Discharges (less than 10 V): These are short, gentle pulses used for:

- Electrolocation: sensing her environment, especially in the murky waters of the Amazon
- Detecting prey and obstacles
- Communication with other electric fish, especially during mating or territorial behaviour

2. High-Voltage Discharges (more than 600 V): These are sharp, rapid bursts used to:

- Stun or paralyse prey such as fish, frogs, and crustaceans
- Defend herself from predators like caimans, crocs and large birds
- Fatigue prey using rapid pulses that trigger muscle twitches, revealing their hiding places

She can even leap from the water and deliver shocks directly to a threat — a tactic rare in the animal kingdom.

Physics beneath the surface:

It's not magic. It's physics. Electra's power is built on the same rules that power your phone:

Ion gradients build potential energy, like charging a capacitor. Series circuits let voltages add up. Ohm's Law determines how far her pulses can travel through water.

But what's astonishing isn't just that she can generate electricity; it's how she controls it. She can fine-tune her shocks, targeting specific frequencies and voltages for different behaviours. Precision that rivals our best machines — built entirely from living cells.

Eel-inspired innovation:

Electric eels have inspired revolutionary research in energy and medicine. Scientists have developed a ***flexible, transparent, and biocompatible power*** source based on the eel's electric organ. Using stacked ***ion-selective hydrogels*** (Fig. 3), this artificial system mimics the eel's ability to generate electricity through ionic gradients. This breakthrough could power ***next-gen implants,*** like pacemakers, sensors, or smart prosthetics, without metal batteries, bringing us closer to organic, body-friendly energy systems. [3]

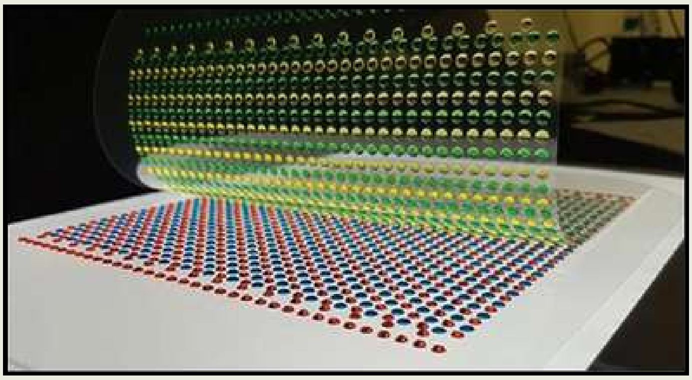

Figure 3: A soft power source was developed inspired by electric eels. The researchers deposited an array of hydrogel droplets onto different plastic substrates, and the superimposed conductive pathways produced a voltage of 110 V. [3]

Conclusion

So, in Electra, we see a living symbol of interdisciplinary electricity science: A creature that blurs the boundaries between zoology and physics, between evolution and engineering.

While scientists build electric circuits with wires and silicon, Electra reminds us that nature did it first — and did it beautifully with flesh, fluid, and evolution.

Electrophorus electricus is a living example that science doesn't only happen in labs. She is a symbol of how life science and physics intertwine — how nature found ways to use the fundamental forces of the universe for survival. As if, in her electric pulses, we hear a message: that even in the deepest rivers and quietest corners of the world, science is always alive, always pulsating and waiting to be discovered.

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From Sand to Silicon

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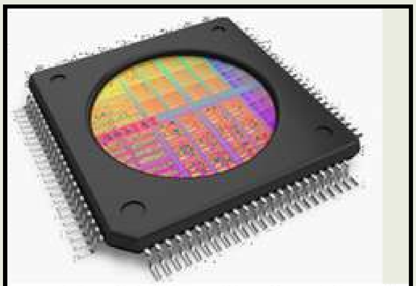
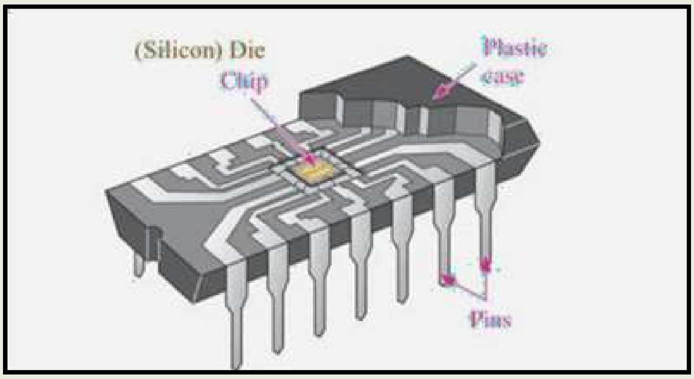
Introduction

In today's groundbreaking era of the computerized world, have we ever wondered how different kinds of electronic gadgets work, or what electricity in the devices. principles of electronic science they follow? What powers our computers, smartphones and so on? Interestingly, they all start from a material, we all know which is 'Sand' and many different metals, by transforming them into technology in the contemporary world. So, sand originally contains silica, which is extracted and purified and turned into pure silicon, which is later used to construct transistors that control.



Manufacturing of the siliconchip

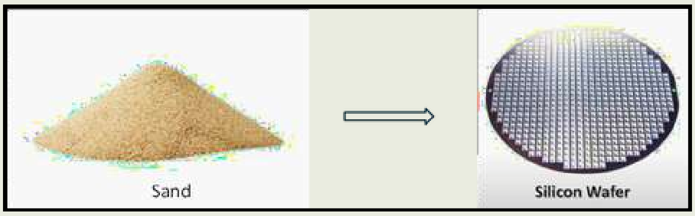


Integrated circuit built using Si chip

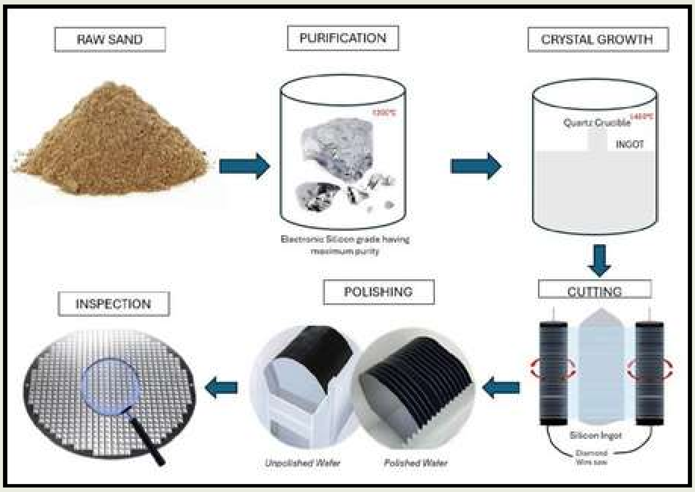
We might already be familiar with the fact that transistors are the building blocks that power these gadgets in our everyday life. Using silicon, we can produce passive components like capacitors, microchips in addition to integrated circuits (ICs), and VLSI (Very Large-Scale

Integrated Circuits), etc. Since the invention of the first chip in 1958, electronics have been continuously integrated into increasingly smaller forms, considering their physical size. At the moment, we have a world of miniaturized devices such as mobile phones, portable chargers and smartwatches. At the same time, we cannot attest to the fact that this is the end of miniaturization, as the demand for advanced VLSI techniques to deliver compact and efficient products will continue for the foreseeable future.

From Sand to Wafer



First of all, how can these tiny grains of sand become a wafer? A chemical elementhaving atomic number14 makes up around 25% of the Earth's crust by mass. Sand is melted down using extreme heat to make the silicon chips. These chips are ultimately the brain of your device, computers to be more precise. Hence, metals like copper (Cu) and gold (Au) are added for wiring, which serve as highways, to facilitate the flow of electricity. So, concerning the making of semiconductors from scratch, that is, from sand, let us delve into the process behind silicon wafer, its manufacturing, from acquiring raw materials to final wafer characterization. Silicon wafer processing refers to the manufacturing steps involved in producing a very high-quality silicon wafer for use in a diverse range of semiconductor devices like microprocessors, memory chips, and sensors. This process mainly involves converting raw materials such as silica sand into pure silicon.

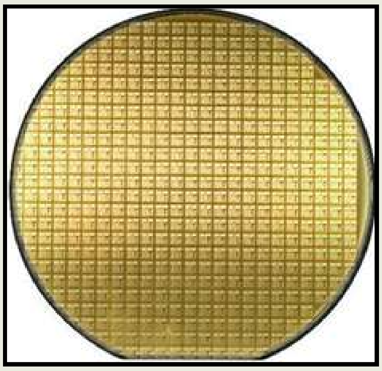


Crystal Growth and Making of Silicon Wafers

The *"Czochralski process"* is used to grow silicon crystals, which are then cut into thin, flat discs. In this, each procedure requires an outstanding level of precision to meet the demands of modern technology. Before being used in semiconductor devices, these discs which are known as 'wafers are carefully cleaned. The performance and dependability of the finished semiconductor products are greatly influenced by the quality of these silicon wafers. The next step is the acquisition of raw materials. The primary raw material used in silicon wafer manufacturing is the 'silica sand', which is abundant in nature.

However, not every type of sand is suitable for manufacturing good quality silicon wafers.

Essentially, the sand must be high in purity, containing lower impurities, like aluminum, iron and other materials to ensure that manufactured silicon wafers result in best quality. Later,these wafers are inspected for possible defects such as cracks, and contamination, that might result in affecting the performance in the semiconductor devices. Similarly, these wafers are tested for their electrical properties like resistivity and are also measured for their thickness in order to meet the specific demands as well as specific parameters while ensuring that they are best suited for semiconductor devices.



Silicon Wafer

The Need for Silicon

Furthermore, more than 90% of the Earth's crust is made up of silicate (silicon dioxide or SiO_2). After oxygen, silicon is the most abundant element beneath our feet. But in the world of modern electronics, not just any silicon will be sufficient. For VLSI technology and silicon chip manufacturing, the silicon must be monocrystalline, with flawless crystal orientation and perfectly uniform chemical properties. This journey begins with carefully curated pure sand. Through a process called 'chemical reduction', oxygen is removed, yielding silicon that is about 98% pure.

High Purity Silicon Powder

Subsequently, this silicon is taken through a series of advanced chemical and mechanical refinements, by removing its additional impurities until they exist only at parts-per-billion levels. The result is very interesting: ultra-pure silicon with a purity of 99.999999999%, a standard so high it's called "eleven nines" in the industry. This purified silicon is formed into long and flawless cylindrical ingots, each being a continuous crystal. Using diamond-edged precision saws, these ingots are sliced into ultra-thin wafers. Hence, wafers are the blank canvases due to which modern electronics come alive.

On each wafer, engineers etch the integrated circuits using dense networks of electrical pathways by linking thousands, sometimes millions, of transistors. A transistor's job is easy and simple; it stores information by either holding an electrical charge in the form of (ON or 1) or not holding a charge (OFF or 0). In essence, each transistor is basically a miniature electric switch, and the language it comprehends is binary language having base 2 as it uses only 2 digits, that is, 0 and 1 respectively.

More often than not, in the course of daily living, we operate in the decimal system, counting from 0 to 9, having 10 as its base. In the digital world, however, this not being the case, say each letter, each number, and every symbol is represented solely by 0s and 1s or has its equivalent binary form in nature. For example, 0101 is the corresponding binary value for the number 5.

Beyond Chips: Fiber Optics

This being the case, silica sand also plays a vital role in making fiber optic cables, which are crucial for high-speed data transmission and telecommunications. The glass core inside these cables is made from high-purity silica, allowing light signals to travel long distances with minimal loss. Thanks to silicas and, fiber optic cables can deliver fast, reliable, and efficient communication, supporting the ever-growing connectivity of our modern world.

Conclusion

In a nutshell, silicon is meticulously extracted from ordinary sand, and thus, today we have built the language of computers, adhering to binary code as well as Boolean logic. It is fascinating how such a simple element has fueled the incredibly wide range of devices right from basic circuits to the vast, interconnected technologies that have helped shape our lives today.

References:

- Geoterra Dominicana
- ResearchGate
- YouTube Channels (*Mr. SMART Engineering, History of Simple things*)

The Magic of Noise Cancellation Headphones

Shrushti Dandi, SYBSc Physics

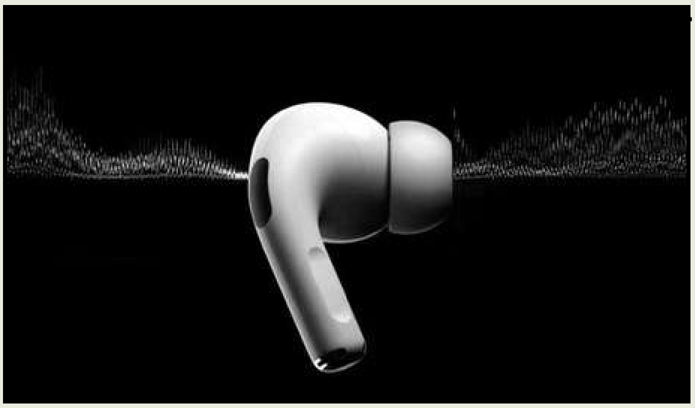
Department of Physics, MES's Nowrosjee Wadia College, Pune 411 001

Ever sat on a crowded bus with an auntie shouting into her phone, a kid kicking your seat, and the driver's Bollywood playlist on full volume and thought, "I wish there was a mute button for life"?

Well, turns out, science kind of made one. It's called Active Noise Cancellation (ANC).

The Simple Idea

We all know sound travels as waves. Noise cancellation takes those same waves and fights them with. more waves. Not louder ones, but opposite ones. Think of it like two ripples in water if a peak meets a dip of the exact same size, they cancel each other out. In physics, it's called destructive interference.



Principle Behind Noise Cancellation

Destructive Interference

The core concept used in Active Noise Cancellation (ANC) is destructive interference, based on the principle of superposition.

Superposition Principle:

When two waves meet at the same point in space, their displacements add algebraically.

Destructive Interference:

If two waves of the same frequency and amplitude are 180° out of phase, they cancel each other out.

Ytotal (t) = A sin(wt) + A sin(wt+) = 0

In other words:

- Wave 1: sin (wt)
- Wave 2: - sin (wt)
- Result: Silence (or greatly reduced amplitude.

Beyond Music

Pilots were some of the first to use ANC to protect their hearing during long flights. Now, students use it to study, commuters to relax, and introverts well, to survive humans.

The Catch

ANC can't block everything, and sometimes people complain of a slight "pressure" feeling in their ears. Plus, it drains battery faster. But for peace of mind? Worth it.

The Quiet Revolution

Noise-cancelling headphones aren't just a gadget they're a tiny example of how physics can make life better. They prove that sometimes, the best way to fight noise. is with more noise, done smartly.

Kamala Sohonie: The First Indian Woman to receive a PhD in a Scientific Discipline.

Kiran Choudhary, TYBSc Physics
Department of Physics, MES's Nowrosjee Wadia College, Pune 411 001

Kamala Sohonie born on 18th June 1911 in Indore, she graduated in 1933 with a B.Sc. degree in Chemistry and Physics from Bombay University. She then applied to the Indian Institute of Science for a research fellowship, but her application was rejected because women in the research field were not accepted during that era in IISc. The faculty of IISc had orthodox thinking,they did not consider women competent enough to pursue research. Kamala responded to the rejection by holding a Satyagraha outside C.V. Raman's office. Raman was then the Director and Nobel Laureate professor in IISc. Her Satyagraha persuaded them to grant her admission, but she wasn't officially a student there, she was on probation for a whole year. The condition kept in front of her was that if her work got accepted by C.V. Raman, only then her admission would be confirmed. She worked hard, proved herself, and got accepted by IISc for her work. After a year, more women came forward and got admission to IISc. There she was under the mentorship of Sri M. Sreenivasayya, where her research focused on the biochemical composition of proteins in milk, pulses, and legumes; foodstuffs of critical nutritional importance in a country where malnutrition was a worrying factor. As a graduate student, she became the first researcher to systematically study pulse proteins.

After her Master's in IISc, her talent was recognized on the international stage. In 1937, she received a research scholarship to pursue her doctorate at the prestigious University of Cambridge. She got admitted to Newnham College and joined the renowned Frederick G. Hopkins laboratory, initially working under the supervision of Dr. Derek Richter. When Dr. Richter departed, she continued her research under the guidance of Dr. Robin Hill, a prominent scientist known for his work on photosynthesis. Focusing her studies on plant tissues, specifically potatoes, Sohonie made a discovery of fundamental importance. She found that the enzyme Cytochrome C, a crucial component of cellular respiration, was universally present in every cell of plant tissue. This discovery established that the enzyme played an essential role in the electron transport chain, the process by which organisms generate energy not just in animals where it was already known, but across the entire plant kingdom. It was a great discovery because it significantly advanced the understanding of plant biochemistry. She completed her research for the PhD and wrote a remarkable 40page thesis. In 1939, she was awarded her PhD, making history as the first Indian woman to earn a doctorate in a scientific discipline from a British university. Her work was so highly regarded that she was then awarded two additional prestigious scholarships: one to continue her research at Cambridge with the Nobel Laureate Professor Frederick Hopkins himself, and a second US traveling scholarship to meet with scientists across Europe.

Leaving it all behind, Kamala chose to return to India and use her knowledge for her country's sake. After she returned, she took upon many good positions at various institutes. She was appointed Professor and Head of the newly established Department of

Biochemistry at Lady Hardinge Medical College in New Delhi. She later served as the Assistant Director of the Nutrition Research Laboratory in Coonoor, where her work focused on the effects of vitamins—a direct application of the research tradition of her Cambridge mentor, Nobel Laureate Frederick Hopkins—to the specific nutritional challenges facing India. The then President Dr. Rajendra Prasad was concerned with widespread malnutrition and sought scientific solutions for the nation. He tasked Dr. Sohonie to investigate the nutritional properties of Neera, which is a common drink in many parts of India. Working with her students at the Royal Institute of Science in Bombay, Dr. Sohonie conducted extensive biochemical analysis of Neera. Her research gave groundbreaking results. She discovered that the drink was a rich source of Vitamin A, Vitamin C, and iron. Perhaps more importantly, she demonstrated that these vital nutrients remained stable and were not destroyed when Neera was concentrated into palm jaggery and molasses. This finding was of immense practical significance. It meant that these inexpensive and widely available products could serve as effective dietary supplements. Subsequent studies confirmed that the inclusion of Neera in the diets of malnourished adolescent children and pregnant women, especially in tribal communities, led to an improvement in their health. For this work, Dr. Sohonie was awarded the prestigious Rashtrapati Award by the President of India. After all of this, she still faced gender bias despite her achievements. Her appointment to the position of Director of the Royal Institute of Science was delayed by four years. Later, when she was appointed, she became the first lady Director in that institute.

She then became a member of the Consumer Guidance Society of India (CGSI), one of the country's earliest consumer protection organizations, which was founded by a group of nine women in 1966. Dr. Sohonie applied her biochemical expertise to the problem of food adulteration that plagued India in the 1970s and 1980s. She was a prominent voice in public education, demonstrating on-the-spot tests to help housewives detect fake ingredients, such as sawdust mixed in powders or the use of 98% aluminium in the silver foil used to decorate sweets. She wrote on consumer safety for the CGSI's magazine Keemat and did not shy away from challenging official standards. She publicly declared the 'nankhatai' biscuits provided to slum children under a state nutrition program as "unfit" for consumption and criticized the "rotten" quality of items sold in government ration shops. Her leadership and commitment were recognized when she was elected President of the CGSI for 1982–83. Beyond her advocacy, she remained committed to science education, authoring several books in the Marathi language to make scientific concepts accessible to young students. She also served as a consultant to the Aarey Milk Dairy in Bombay, where she developed protocols to improve milk quality and prevent curdling.

In 1997, she received the National Award for Excellence and Contribution to Science. This was followed in 1998 by the felicitation ceremony organized by the Indian Council of Medical Research in New Delhi. During the felicitation, she collapsed while delivering a lecture and died shortly after. That day, India lost a gem, a woman who never gave up, a woman who was compassionate, a woman who was an inspiration to many.

Kamala Sohonie's life is a real example of courage, commitment, and service to her country. She overcame challenges when women weren't given opportunities in science and showed her strength through groundbreaking research. Her work in biochemistry, nutrition, and consumer safety is still very important, and her story continues to encourage young scientists today. She proved that with hard work and love for her field, no challenge is too big, and her impact will always be remembered in the history of Indian science.

Tata Institute of Fundamental Research (TIFR): A Pillar of Scientific Excellence in India

Team BHOUTIKI
Department of Physics, MES's Nowrosjee Wadia College, Pune 411 001

When it comes to physics research in India, one name stands out: the Tata Institute of Fundamental Research (TIFR). Founded in 1945 by Dr. Homi Jehangir Bhabha, TIFR has become the nation's leading center for fundamental science, with physics at its core.

The Beginning

In a time when India had limited options for advanced research, Homi Bhabha envisioned a world-class institute where Indian scientists could explore basic questions about nature. With support from the Tata Trusts and later the Government of India, his dream became a reality with the establishment of TIFR in Mumbai. Since then, TIFR has played a key role in shaping physics research in the country.

Physics at TIFR

From the beginning, TIFR prioritized physics in its research agenda. The institute's work covers many areas:

- Nuclear and Particle Physics: TIFR was crucial in starting India's nuclear research program, which later led to the formation of BARC. Its scientists have also contributed to global projects like experiments at CERN.
- Astrophysics and Cosmology: The National Centre for Radio Astrophysics (NCRA), part of TIFR, operates the Giant Metrewave Radio Telescope (GMRT) near Pune. This is one of the world's largest and most sensitive radio telescopes. It has provided new insights into galaxies, pulsars, and the large-scale structure of the universe.
- Condensed Matter Physics: TIFR researchers investigate materials at the quantum level, improving our understanding of superconductivity, magnetism, and nanoscience.
- Theoretical Physics: From quantum mechanics to string theory, TIFR has nurtured some of India's best theoretical physicists. The International Centre for Theoretical Sciences (ICTS) in Bengaluru further explores this field.

Training Future Physicists

TIFR is not only a research center but also a university. Through its PhD and integrated PhD programs, it trains young physicists to become independent researchers. Students collaborate closely with leading scientists and work on current challenges in modern physics. Admission is very competitive, attracting talent from all over the country.

Impact Beyond the Lab

TIFR's contributions to physics go well beyond academic papers. It has influenced India's nuclear energy program, aided space research, and developed international collaborations that elevate Indian physics on the global stage. Its outreach division, the Homi Bhabha Centre for Science Education (HBCSE), has also motivated school students by preparing them for international physics Olympiads.

Conclusion

For nearly eight decades, the Tata Institute of Fundamental Research has been a cornerstone of physics in India. From investigating the mysteries of the cosmos to studying the strange world of quantum mechanics, TIFR embodies a spirit of curiosity and discovery. It is a place where remarkable physics is conducted and where the future of Indian science continues to unfold.

Institute Images

Institute Logo

Mumbai Campus

Main Building

High Energy Physics Laboratory

Nuclear & Atomic Physics Laboratory

NCRA TIFR

Drone Workshop by DroneAcharya Aerial Innovations

BHOUTIKI The Physics Club

Department of Physics, MES's Nowrosjee Wadia College, Pune 411 001

The seminar on drone technology, jointly organized by Modern Education Society's Nowrosjee Wadia College, Pune and the BHOUTIKI Club, in collaboration with DroneAcharya Aerial Innovations, was held on 6th August 2025 at Tata Assembly Hall. Coordinated by Dr. V. V. Antad from the Department of Physics, the event aimed to introduce students and faculty to the evolving landscape of drone design, applications, and entrepreneurship. Experts from DroneAcharya showcased real-time drone models, explaining aerodynamic principles and structural design. Participants engaged in hands-on training, assembling components and piloting demo drones. The seminar highlighted diverse drone applications in agriculture, surveillance, logistics, and environmental monitoring, while also exploring startup opportunities and regulatory frameworks. Ethical concerns and future challenges in drone technology sparked thoughtful discussions. Over 200 students from Physics, Electronics, Computer Science, and Engineering departments attended, with BHOUTIKI volunteers facilitating logistics and interaction. Feedback revealed 95% satisfaction, with strong interest in follow-up workshops and certifications. The event bridged theoretical knowledge with practical innovation, inspiring interdisciplinary projects and potential collaborations with DroneAcharya for internships and outreach. Gratitude was extended to the trustees, principal, faculty, technical team, and volunteers for their seamless coordination and to DroneAcharya for their dynamic engagement.

Voltage Noir

In the labyrinth of circuits, a maze so vast,
Echoes of our humanity, a fading past.
Yet within this darkness, a beacon bright,
A testament to our enduring light

The rhythm of life, now a digital beat,
In the heart of silicon, where pulses meet.
Yet within each byte, each coded line,
The human spirit continues to shine.

The echo of laughter, the trace of a tear,
In the binary code, they appear.
Yet they're but shadows, hollow and cold,
Of the human story, ageless and bold.

The machine may mimic, replicate and learn,
Yet the fire of life, it cannot earn.
For within each of us, a universe vast,
A testament to our timeless past.

In the heart of the machine, a void so deep,
Where dreams of silicon silently sleep.
Yet within this abyss, a stark reminder,
Of the world we've left behind us.

Yet fear not this future, dark and grim,
For the light of hope is never dim.
In the dance with tech, let's lead the way,
For we are the dawn of a brighter day.

In the heart of the night, a promise we make,
To remember what's real, what's at stake.
For we are more than data and code,
Who are the writers of the future's ode?

Harsh Ugale
Department of Physics, MES's Nowrosjee Wadia College, Pune 411 001

Semiconductor

Once every two years,
The transistor shrinking out of sight
no moving arm, no ticking core
Logic flows from gate to shore.
Bais bends the bands beneath
Modulates the carrier sheath
A threshold crossed and unlocks,
Gates, the current flows from source to box
You house the world,
we are living a nanofrinch

Deepa K
Department of Physics, MES's Nowrosjee Wadia College, Pune 411 001

The Heart of Modern Day

In silicon veins and crystal light,
Where electrons hustles day and night,
A world unfolds so small, so grand,
Where science sculpts with steady hand.

Not quite a metal, not an insulator,
A bridge to all, a smooth translator.
It knows when to flow, when to resist,
A mindful gate within the mist.

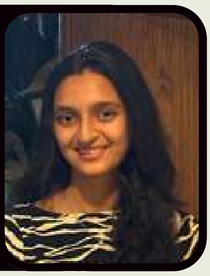
From doped domains with N and P,
It crafts the path for circuitry.
The chip, the brain, inside your phone,
Would be just glass and lifeless stone.

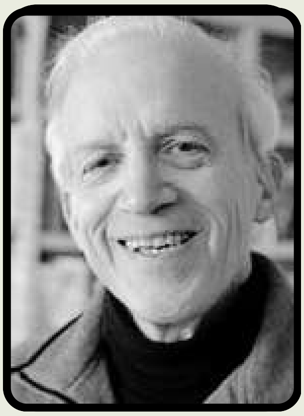
In labs and fabs they forge the core,
Of AI, dreams, and so much more.
Billions of them, all on one chip,
Like engineers on a caffeine trip!

Komal Pareek, M.Sc. Physics
Department of Physics, MES's Nowrosjee Wadia College, Pune 411 001

"From Atoms to Superconductors: A Tribute to Kleppner and Giaever"

Vidhi Baldota, TYBSc Physics
Department of Physics, MES's Nowrosjee Wadia College, Pune 411 001





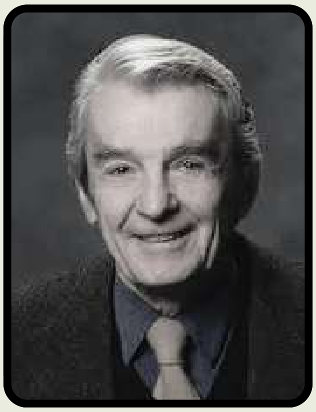
(1932-2025)

Daniel Kleppner

Daniel Kleppner, born on December 16, 1932, in New York City, and passed away on June 16, 2025. He was one of the foremost figures in atomic, molecular, and optical physics. A protégé of Nobel laureate Norman Ramsey at Harvard, he made his early mark with the development of the hydrogen maser, a device that became a cornerstone of atomic clocks and precision timekeeping.

Over his long career at MIT, where he served as the Lester Wolfe Professor of Physics, Kleppner continually pushed the boundaries of experimental techniques, probing the quantum structure of matter with extraordinary ingenuity. Among his most influential contributions were his pioneering studies of Rydberg atoms, whose exaggerated quantum states offered a powerful testing ground for atomic theory and quantum electrodynamics. He also laid essential groundwork for the eventual realization of Bose-Einstein condensation in ultracold gases, research that reshaped the trajectory of modern quantum physics.

Beyond his scientific discoveries, Kleppner was deeply admired as a teacher and mentor. His lucid lectures, thoughtful guidance, and enthusiasm inspired generations of physicists, many of whom went on to make groundbreaking contributions of their own. His intellectual clarity and generosity of spirit ensured that his influence will continue to resonate across the global scientific community.



(1929-2025)

Ivar Giaever

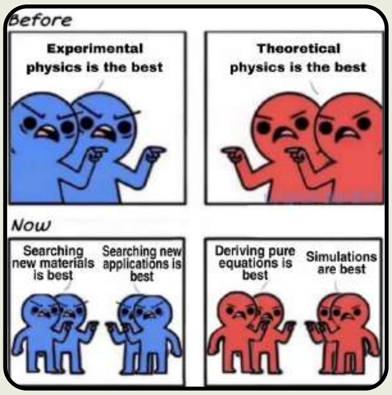
Ivar Giaever, born on April 5, 1929, in Bergen, Norway, and passed away on June 20, 2025. He was awarded the 1973 Nobel Prize in Physics for his discovery of electron tunneling in superconductors. His elegant experiments at the General Electric Research Laboratory provided the first direct experimental confirmation of the Bardeen-Cooper-Schrieffer (BCS) theory, one of the cornerstones of modern condensed matter physics. By demonstrating how quantum tunneling could probe the energy gap in superconductors, Giaever opened a new experimental window into the microscopic workings of quantum materials.

Following his Nobel prize winning research, Giaever broadened his scientific interests to thin films, tunneling in semiconductors, and later to biophysics, where he applied physical principles to biological systems. His career was marked by boldness, technical creativity, and an never-ending curiosity that led him to cross traditional disciplinary boundaries with ease.

Giaevers legacy extends beyond his discoveries, to the example he set for the scientific community: a spirit of independence, experimental rigor, and intellectual courage. His contributions transformed our understanding of superconductivity and left a lasting impact on both physics and interdisciplinary research.

Physics Memes

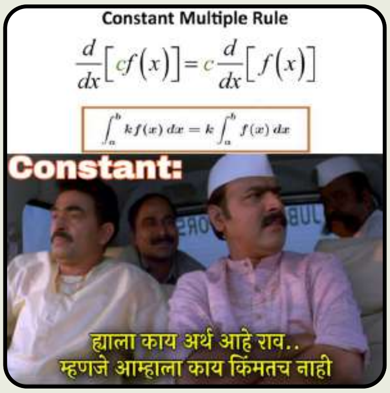
Shubham Jadhav
Department of Physics, MES's Nowrosjee Wadia College, Pune 411 001



New Rivalries in research

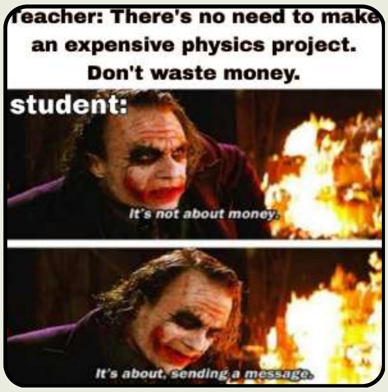
Frequency approximately equal to 50 Hz

In pn junction diode, depletion region avoids recombination of electron and holes.



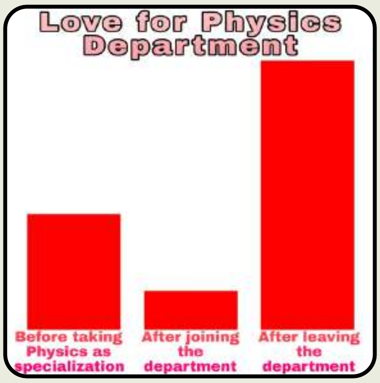
Röntgen gave us X-rays.
Cancer came free of charge.

Rutherford discovered proton and Chadwick discovered proton



A project is not a project until it is costly.

Gotcha!



You miss the department most after leaving it

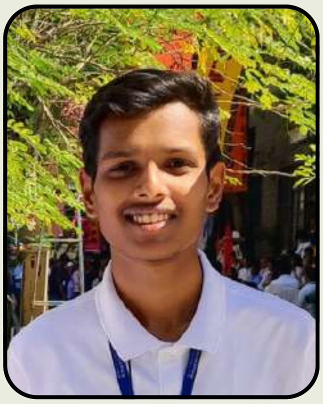
The author is an Assistant Professor (Ad-hoc) in the Department of Physics at Nowrosjee Wadia College. An esteemed alumnus of our department, he specializes in Computational Physics and Theoretical Physics, while also excelling as a creative content creator.

Prof. V. G. Bhide Memorial Lecture

BHOUTIKI The Physics Club
Department of Physics, MES's Nowrosjee Wadia College, Pune 411 001




On 30th August 2023 at 11:00 AM, the Maharashtra Academy of Sciences (MASc), Pune, in collaboration with MES's Nowrosjee Wadia College – Department of Physics and the BHOUTIKI Physics Club, organized a commemorative lecture at the Tata Assembly Hall, Nowrosjee Wadia College, Pune. Coordinated by Dr. S. S. Warule, the event honored the enduring legacy of Prof. V. G. Bhide and aimed to inspire students and faculty alike through a captivating talk by **Dr. Ravikumar Verma, Scientist at the Space Applications Centre, ISRO Ahmedabad.** Dignitaries present for the event were Dr. B. B. Kale; Vice President, MASc, Dr. V. V. Chabukswar; Principal, NWC, Dr. B. B. Bahule; Vice Principal, NWC, Dr. S. A. Boxawala Kale; Vice Principal, NWC, Dr. Arbuj; Secretary, MASc, Prof. S. G. Jamdade; Head, Dept. of Physics, NWC, Dr. S. S. Dhandore; Vice Principal, Jr. College, NWC.
The lecture delved into India's remarkable space journey, tracing its historical foundations, showcasing current technological strides, and envisioning future aspirations, thereby fostering scientific curiosity and national pride among the attendees.



Mr. Yash Bundile

One of our department's bright students, **Mr. Yash Bundile** brought laurels by qualifying for and attending the prestigious **BRICS Astronomy Summer School.** This international program provided a platform to learn from leading experts and collaborate with peers from BRICS nations. The student actively engaged in lectures, discussions, and workshops on contemporary themes in astronomy and astrophysics, gaining exposure to the latest research methodologies. Under this he activly started his individual project on **"Identification and Characterization of Rare Stellar Populations in ESA Gaia DR3 Using Machine Learning"**.As part of the program, they also worked on projects involving data analysis, computational techniques, which enriched their technical and research skills.

The experience not only broadened their academic horizons but also instilled confidence in pursuing research at an international level. Following the summer school, the student continued to apply these learnings in departmental projects, further strengthening their contribution to the field. This achievement stands as a testament to their dedication and also reflects the encouragement and support provided by the department. It serves as an inspiration for fellow students to explore global opportunities and to carry forward the spirit of innovation.

Our department's bright students, Mr. Anurag Mehta and Ms. Vidhi Baldota had remarkable achievement at Avishkaar 2025. Their research poster, exploring the **"Predictive Analysis of Human Vision through Biopotential Signals",** impressed the college-level jury, securing their 1st position victory and a place in the upcoming zonal rounds. Their innovative work demonstrates a sophisticated approach to decoding visual processing, showcasing exceptional promise in the field of biophysics. We wish them the very best for the next stage of the competition.

Ms. Vidhi Baldota

Mr. Anurag Mehta

We take immense pride in congratulating our students who secured research funding from Nowrosjee Wadia College. Their dedication, innovative thinking, and consistent efforts have been recognized through this prestigious support. Receiving such funding at the student level is not only an encouragement for their individual projects but also a mark of the strong academic culture nurtured within our department.

These students have shown exceptional initiative in taking their ideas beyond the classroom and working towards real-world applications. Their achievement reflects both their commitment to research and the guidance of faculty mentors who have supported them throughout this journey. We believe that such milestones will inspire many more of our students to explore new frontiers in science and innovation, carrying forward the proud legacy of the department.

REVIEWS

It's a pleasure to contribute to the Bhoutiki Padyna magazine, a commendable initiative by the Bhoutiki team. These activities are crucial not only for discovering and nurturing talents but also for attracting new people to the field of physics- a fundamental science essential for national development..The magazine's inaugural issue is engaging, featuring a wide array of content from traditional articles to modern memes. This variety, along with contributions from various academic and professional levels, enriches the publication and ensures high quality. I am confident that this quality will continue or perhaps improve in future issues, given my knowledge of some of the key people behind Bhoutiki in professional and personal capacity.A truly complete review includes honest, constructive criticism for future improvement. In this regard, I found the double-toned colored pages slightly over-designed. They occasionally create a sense of reading discontinuity and can provide a false sense of highlighting in some articles.

Finally, I want to congratulate the team on their first published issue and for launching Bhoutiki's activities. These initiatives are a necessary and important addition to the Department of Physics, Nowrosjee Wadia College.

-Prof. Sanket Gogate, Modern College, Pune

The biophysics themed volume of Bhoutiki Pradnya is a refreshing blend of science and creativity, showing how physics connects with life sciences in exciting ways. The articles are diverse and easy to follow, touching on health, nanotechnology, space, and more making the subject feel alive and relevant. What makes it special is the teamwork behind it: students, alumni, and experts have clearly put in great effort in writing, editing, and shaping the issue. Their hard work shines through, making this volume both enjoyable and inspiring to read. For young readers, it serves as a wonderful introduction to the fascinating world of biophysics and its future possibilities.

-Dr. Sagar Jagtap,
H. V. Desai College, Pune

"Bhoutiki Pradnya, the quarterly news letter launched by the students of Physics Department, is a commendable effort. Its a great platform to share knowledge and perspectives. The articles are well-written, informative and overall quality is an impressive, reflecting the hard work and dedication of the entire team. I appreciate the initiative taken by Physics teachers to encourage students and wish the team all the best for future mile stones. It's a valuable asset for Department of Physics, Nowrosjee Wadia College.

-Dr. Abhijit Limaye, NWC

I'm thoroughly impressed with the previous and latest issues of Bhoutiki Pradnya! The articles are informative, well-researched, and engaging. Specially Students articles are interesting.The format is visually appealing, and the editorial team has done a fantastic job in bringing out the best in every section. Kudos to the entire team for their hard work and dedication. Excited for for the next issue!

-Prof. Harshada Nagargoje, NWC

BHOUTIKI PRADNYA stands out as a vibrant, student-driven initiative that brings together diverse voices from across the physics community. Its thematic focus in each special edition reflects both intellectual depth and editorial clarity. Contributions from professors, scientists, alumni, and students ranging from undergraduate to postgraduate create a rich tapestry of perspectives. The format is engaging and well-structured, and the newsletter’s drive to foster curiosity and collaboration in physics is truly commendable. This drive should reach to all youngsters those pursue Science stream.

-Dr. Shashikant Shinde, NWC

'Bhoutiki Pradnya' is a phenomenal effort by the Bhautiki Club; it's truly impressive! Students taking the lead and growing interest as authors is inspiring. The club provides an outstanding platform for showcasing knowledge and passion for physics. Each issue is exceptional, with well-researched articles balancing depth and accessibility. The visually appealing format engages readers perfectly. What stands out most is the editorial drive, it's clear that the team is passionate about physics and dedicated to sharing that enthusiasm with others. The articles cover a wide range of topics, from the latest research to thought-provoking discussions. Kudos to the Bhautiki Club team for creating such an outstanding publication that inspires and educates readers. Wishing them all the best for future endeavors and looking forward to many more successes!

-Dr. Supriya Patade, NWC

BHOUTIKI PRADNYA is a very well-prepared magazine with interesting and useful articles. The quality of the content is good and easy to connect with. Its simple format and clear presentation makes it enjoyable to read. The editorial team has done a wonderful job in bringing out such an inspiring issue.

-Amit Pokharkar, JSPM, Hadapsar

BHOUTIKI PRADNYA is a commendable initiative by our Physics Department aimed at delivering the complex scientific knowledge into simple, accessible language. I truly believe this platform will be immensely beneficial—not only for the students who contribute to this quarterly magazine, but also for those who engage with it. It fosters scientific curiosity, communication skills, and a deeper understanding of physics in a way that's both meaningful and inspiring.

-Dr. Kiran Wani, IIA Bengaluru

Bhoutiki Pradnya has always been a pleasure to read, with its insightful articles and simple, reader-friendly format. It has been a real source of impactful knowledge.
Writing my first-ever physics article for this magazine was a wonderful and enriching experience. I am very grateful to the entire team for giving me this opportunity, which has boosted my confidence to share my thoughts and learning.
I sincerely wish the September issue great success.

-Rupali Khomne,
Abasaheb Garware College

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Nuclear Physics

December Issue

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