

Dr. Saima Beg is an Associate Professor in the Department of Electronics and Communication Engineering at Integral University, Lucknow. She holds a Ph.D. and M.Tech. from Integral University and a B.Tech. in Electronics Engineering from Aligarh Muslim University. Her academic and research interests include VLSI technology and electronic circuit design. With extensive teaching experience, she is actively involved in teaching, research, and academic development, contributing to the advancement of technical education and the professional growth of students.



Dr. Mohd. Suhaib Kidwai is an Associate Professor in the Department of Electronics and Communication Engineering at Integral University, Lucknow. He is an accomplished academician and researcher with expertise in biomedical signal processing, particularly in the detection of neurological disorders using electroencephalogram (EEG) signals. His research focuses on applying machine learning algorithms, MATLAB, and Python for the analysis of brain signals and neurological conditions. He has contributed to scholarly publications in Scopus-indexed journals and IEEE conferences and has also published a patent and a book related to neurological disorder detection. His academic and research contributions reflect his commitment to advancing interdisciplinary research and technological innovation.



Dr. Shailendra Kumar is an Associate Professor in the Department of Electronics and Communication Engineering at Integral University, Lucknow, Uttar Pradesh. His areas of expertise include VLSI (Very Large-Scale Integration) and Video Processing. His teaching areas encompass Electronics Engineering, Network Analysis, Control Systems, Signals and Systems, Communication Systems, Digital Electronics, and Modelling and Circuit Simulation. He is also associated with the Communication System research group of the department. In addition to his academic and research activities, Dr. Kumar has contributed to departmental quality assurance and academic administration. According to a university notice dated June 3, 2025, he was nominated as Chairman of the Departmental Quality Assurance Committee (DQAC) for the 2025–2026 academic session. His professional profile reflects his involvement in teaching, research, and quality enhancement activities at Integral University.

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Dr. Saima Beg
Dr. Mohd Suhaib Kidwai
Dr. Shailendra Kumar

Polymer Electronics: Materials, Device Physics, Processing Technologies, Applications, and Emerging Trends

Ayan Mustafa Khan[1], Saima Beg[2], Suhaib Kidwai[3], Syed Hasan Saeed[4]

[1234]Department of Electronics and Communication Engineering, Integral University, Lucknow-226026

Abstract

Polymer electronics has developed from the early study of electrically conducting plastics into a broad materials and device platform encompassing conjugated semiconductors, intrinsically conducting polymers, polymer dielectrics, ionic conductors, electroactive polymers and multifunctional polymer nanocomposites. Its technological value comes from combining electronic or electrochemical functionality with low density, mechanical compliance, chemical tunability, solution processability and compatibility with low-temperature or large-area manufacturing. This chapter provides a research-oriented review of polymer electronics, covering molecular structure, doping, charge and ion transport, morphology, interfaces, fabrication, device physics, reliability and applications. Particular attention is given to PEDOT:PSS, polyaniline, polypyrrole, P3HT, donor–acceptor conjugated polymers, polymer dielectrics and organic mixed ionic–electronic conductors. Major devices—including organic field-effect transistors, organic electrochemical transistors, polymer light-emitting devices, organic photovoltaics, thermoelectric generators, sensors, memories and soft bioelectronic interfaces—are compared using representative performance metrics. Mathematical relationships for conductivity, field-effect transport, OECT transconductance, photovoltaic conversion, thermoelectric

performance and strain sensing are introduced. Recent literature from 2020–2026 is synthesized to identify trends in flexible and wearable electronics, biointegration, printed manufacturing, neuromorphic computing, sustainability and molecularly engineered polymer semiconductors. The analysis shows that future progress will depend less on maximizing a single material property and more on co-optimizing molecular structure, film morphology, contacts, mechanics, packaging, process variability and system requirements. Major unresolved issues include long-term environmental stability, n-type transport, device-to-device variation, scalable patterning, reliable encapsulation, sustainable materials processing and end-of-life management. The chapter proposes a materials-to-system research framework that can guide experimental studies and technology translation.

Keywords: polymer electronics; conducting polymers; conjugated polymers; PEDOT:PSS; organic semiconductors; flexible electronics; OECT; OFET; organic photovoltaics; wearable electronics; printed electronics; bioelectronics; mixed ionic–electronic conductors.

1. Introduction

Modern electronic systems are increasingly expected to operate outside the rigid form factors associated with conventional silicon-based electronics. Wearable sensors, electronic skins, soft robots, smart textiles, conformal displays, flexible energy harvesters and implantable biointerfaces require materials that can simultaneously provide electrical function and mechanical compliance. Polymer electronics addresses this requirement by exploiting polymers not only as structural or insulating materials but also as active electronic, optical, ionic and electrochemical components. Recent reviews emphasize that polymer-based flexible electronics now spans material physics, advanced patterning, wearable systems and bio-integrated devices, with stability, scalability and biocompatibility remaining important challenges [1].