Organic and Hybrid Organic-Inorganic Materials and Devices for Integrated Photonics

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Traditionally, integrated photonic systems have been made from crystalline, inorganic semiconductors, such as silicon and compound semiconductors, for application to optical communication. Beneficial material properties, such as high-speed response, efficient conversion of light energy, and stability over time, have helped establish inorganic semiconductors as the dominant materials class for such applications. Despite the elemental composition of these inorganic semiconductors that can sometimes be toxic and rare, or the ultra-high vacuum and high-temperature conditions that can be required for material processing, these expensive photonic technologies are used in many industrial and commercial products because the device areas required for optical communication applications are very small.

Yet, optical communication is not the only application of integrated photonics. Biomedical sensors that detect changes in the optical properties of biological samples can be used to diagnose diseases. High-resolution, digital displays that emit bright light with excellent color quality are important components of consumer electronics. Solar cells that convert absorbed sunlight into electricity are critical for meeting the energy needs of the future. Each of these applications could benefit from inexpensive, large area devices with flexible form-factors. In addition, the ability to combine multiple photonic devices with very different functions on a single substrate, like paper, textiles, or glass, could enable new integrated systems.

Organic semiconductors, or synthetic, carbon-based molecules, are well-suited to these desired characteristics. These organic materials feature the definitive characteristic of a semiconductor, namely, an energetic bandgap across which light can be absorbed and emitted and which enables the conduction of charge. While organic photonic devices are not ideal for the high-speed device requirements in optical communication, they can provide efficient conversion of light energy and designer functionality and optical properties. Organic materials also benefit from the potential for synthesis by sustainable and non-toxic chemistry using inexpensive, earth-abundant raw materials. In addition to organic semiconductors, hybrid organic-inorganic materials can enable new approaches to integrated photonics. The most common hybrid material system is that of inorganic semiconductor nanoparticles embedded in an organic semiconductor, known as a hybrid nanocomposite. These materials are important because disparate properties in the organic and inorganic constituents can be combined to create new materials with tailored characteristics.

While there is great potential for integrated photonics based on organic and hybrid materials, there are a few fundamental challenges facing this technology. First, the photonic properties of a synthesized organic molecule often change when the material is incorporated into a film for device applications, and the ability to predict device performance is often hampered by the variation in film behavior based on deposition technique. Second, while organic and hybrid materials benefit from simple solution-processing that is very amenable to large-area, roll-to-roll manufacturing, it has proven difficult to control the device performance over these large areas such that high-yield, high-throughput production is achieved. Third, many organic materials are sensitive to ultraviolet light and moisture such that device performance in the field can degrade rapidly, resulting in system lifetimes that are not practical for certain applications.

Nonetheless, organic and hybrid organic-inorganic materials provide an exciting pathway for incorporating integrated photonics into new technologies with the potential to revolutionize how people interact with devices based on the generation, detection, and manipulation of light.