NANODEVICES IN OPTOELECTRONICS

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Over the past decade, there has been a growing interest in novel materials, including graphene derivatives, transition metal dichalcogenides (TMDs), two-dimensional (2D) layered materials, perovskites, metal oxides, and other metal nanostructures [1–4]. These materials possess exceptional physical, optical, thermal, and electrical properties due to their 2D ultrathin atomic layer structure, large interlayer distance, ease of functionalization, and bandgap tunability. They have found applications in various rapidly expanding fields such as energy (photovoltaics, energy storage, fuel cells, hydrogen storage, catalysis, etc.), electronics, photonics, spintronics, and sensing devices [5–8]. Their continuous use in nanostructure-based applications has led to significant improvements in existing products and the exploration of novel functionalities [9–11].

This Special Issue presents the latest trends and advancements in the interdisciplinary field of optoelectronics, featuring 24 original research articles and two review papers. Most articles focus on light-emitting diodes (LEDs) and solar cells (SCs), encompassing organic, inorganic, and hybrid configurations. Additionally, some articles delve into photodetectors, transistors, and other dynamic optoelectronic devices, as illustrated in Figure 1. This exceptional collection is intended for a broad scientific audience, including chemists, materials scientists, physicists, and engineers, aiming to highlight the potential of innovative optoelectronic applications incorporating nanostructures and inspire their realization.

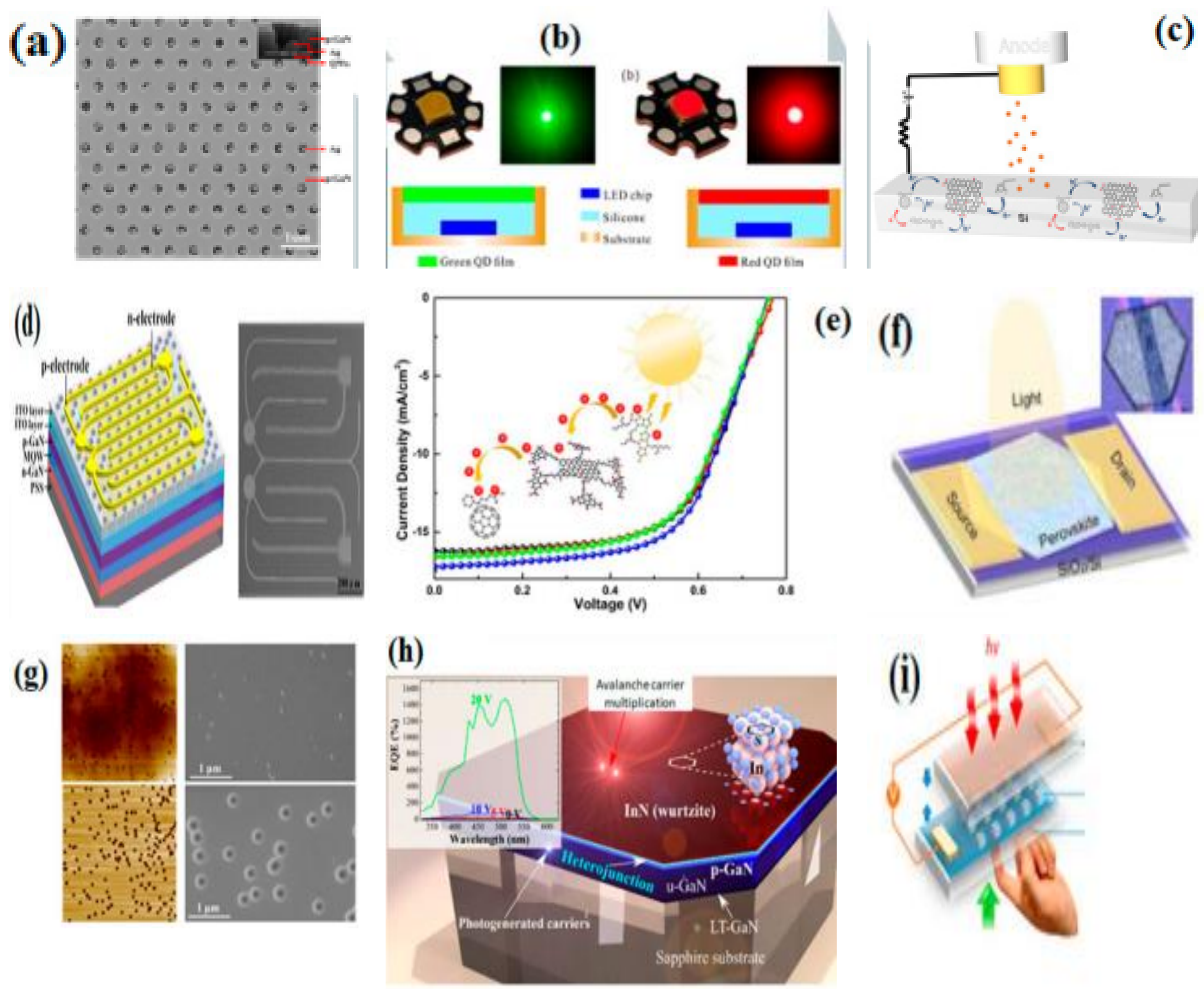
The first section of this special issue comprises five original articles within the solar cell technology domain. To begin, Deng et al. [22] discuss their work on creating a Ti porous film-supported NiCo2S4 nanotube, serving as an effective counter electrode (CE) in CdS/CdSe quantum-dot-sensitized solar cells (QDSSCs) as an alternative to the conventional FTO/Pt counterpart. This innovative porous CE, fabricated using acid etching and a two-step hydrothermal method, displayed superior electrocatalytic properties, increased loading capacity, and enhanced stability, resulting in a remarkable 240% enhancement in photovoltaic performance compared to the standard FTO/Pt-based configuration.

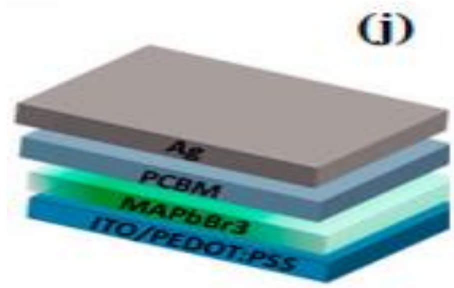
Following this, Ho et al. [23] detail their endeavors to enhance the performance and power output of textured silicon solar cells through plasmonic forward scattering. They introduced single and double layers of two-dimensional indium nanoparticles (In NPs) within a SiNx/SiO2 double-layer antireflective coating. As a result, both approaches yielded improved conversion efficiency, up to 5% enhancement compared to the reference cell.

They further explored the impact of In NPs layers within the double layer of ARC on light-trapping performance at varying angles, and the electrical output power exhibited an impressive increase of over 50%.

In a separate study, Shi et al. [24] present their work on growing high-performance ultrathin MoO3/Ag transparent electrodes through thermal evaporation at various deposition rates, evaluating their optical, electrical, and morphological characteristics. Their findings demonstrated that the synergistic combination of MoO3 with silver, even as a thin nucleation layer, was advantageous for producing uniform, semitransparent, and highly conductive porous films. These ultrathin electrodes were utilized as top semitransparent electrodes in inverted organic solar cells, resulting in a significant photovoltaic performance (2.76%) when illuminated from the top side.

Lastly, Svrcek et al. [19] discuss their research on developing low-roughness InN thin films using the pulsed metalorganic vapor-phase epitaxy (MOVPE) process. The optimized InN/p-GaN photoelectric heterojunction exhibited exceptional electron extraction efficiency, surpassing comparable studies based on pulsed MOVPE in the literature.





Showcases a variety of optoelectronic device configurations featured in this Special Issue.

(a) Presents a scanning electron microscope (SEM) image of an Ag–photonic crystal (PhC). Reproduced with permission from [12]; (b) Provides both real representations and schematic diagrams of green and red quantum-dot light-emitting diodes (LEDs). Reproduced with permission from [13]; (c) Displays a representation of a field emitter cold cathode utilizing graphene oxide r(GO):organic charge transfer materials composites. Reproduced with permission from [14]. (d) Offers a schematic representation of a patterned double-layer indium tin oxide (ITO) ultraviolet (UV) LED. Reproduced with permission from [15]; (e) Illustrates typical J-V curves of a ternary organic solar cells (OSC) device and a schematic representation of charge transfer between active layer materials. Reproduced with permission from [16]; (f) Depicts a schematic representation of a two-dimensional (2D) perovskite platelet phototransistor. Reproduced with permission from [17]; (g) Displays atomic force microscopy (AFM) and SEM images of green LEDs with and without InGaN/GaN superlattice. Reproduced with permission from [18]; (h) Shows a schematic representation of an InN/p-GaN photoelectric heterojunction. Reproduced with permission from [19]; (i) Highlights the configuration of a CdTe microdots array photodetector. Reproduced with permission from [20]; (j) Introduces the configuration of a light-emitting diode (PeLED) based on octylammonium substituted perovskite. Reproduced with permission from [21]. Copyright for all figures is held by MDPI publisher, 2020.

The ternary configuration has displayed significant potential within the realm of organic solar cells. Stylianakis et al. [16] introduced a novel graphene derivative with energy levels compatible with the binary blend materials typically used in the active layer of inverted organic solar cells. This newly developed graphene-based molecule was integrated in ink form as the third component within the active layer in various ratios. This innovative approach led to the creation of highly efficient inverted ternary organic solar cell (OSC) devices, demonstrating a notable performance enhancement of 13% compared to the control device, resulting in a record-breaking power conversion efficiency (PCE) value of 8.71%. The improvement in PCE was attributed to the cascade effect, facilitating electron transport from the active layer to the ITO bottom electrode, along with enhanced morphology at the interfaces of the binary blend components. In the same section, Chen et al. [25]

investigated the impact of solvent polarity and the concentration of the precursor methylammonium iodide (MAI) on the morphology of MAPbI3 perovskite thin films. Their findings revealed that the longer alkyl chain of the solvent (lower polarity) led to improved coverage and compactness, albeit with higher film roughness. Following parameter optimization, they achieved highly efficient perovskite solar cells with a champion PCE of 16.66%.

Moving on to the second section, which comprises ten original contributions focused on LEDs, Feng et al. [12] explored the combination of localized surface plasmon (LSP) and quantum wells (QWs) by incorporating silver NPs into the holes of a photonic crystal within the p-GaN layer of a green LED. They employed a 3D finite difference time domain (FDTD) numerical simulation model to assess the impact of light and e-beam-induced excitations on LSP–QW coupling and suggested ways to reduce energy dissipation in Ag NPs.

Yan et al. [13] evaluated the performance of green and red CdSe quantum dots (QDs)-based LED devices under various excitation wavelengths by studying the photoluminescence (PL) of thin films. Liu et al. [18] investigated the role of a V-pits-embedded InGaN/GaN superlattice (SL) in improving the external quantum efficiency (EQE) of green LEDs, achieving an enhancement of approximately 30%. They utilized scanning electron microscopy (SEM) and room temperature cathodoluminescence (CL) to validate the light emission properties of InGaN/GaN multiple quantum wells (MQWs), demonstrating that V-pits acted as barriers for carriers' diffusion into non-recombination centers. Chen et al. [21] prepared highly fluorescent and uniform MAPbBr3 thin films by adjusting the octylammonium bromide (OAB) additive content in the perovskite precursors, leading to the fabrication of high-performance perovskite-based LEDs with exceptional luminance and luminous current efficiency values, attributed to the high exciton binding energy of the nanocrystals' grain size, which mitigated nonradiative recombination and enhanced emission efficiency.

Li et al. [26] reported on their efforts to improve the color-conversion efficiency (CCE) and stability of quantum-dot-based light-emitting diodes by incorporating a blue anti-transmission film (BATF). Their findings demonstrated that by optimizing the BATF thickness and QDs concentration, both CCE and luminous efficacy could be significantly improved, by over 42% and 24%, respectively. Zhou et al. [27] proposed the design of two novel p-type layers, a gradually reduced indium content p-InGaN and a p-GaN, to enhance the light output power of a GaN-based green LED. The champion green LED device exhibited a remarkable ~14% improvement in light intensity compared to the reference device as the indium content was gradually reduced from 10% to 0%, supported by experimental and simulation studies. In another theoretical study on GaN-based LEDs, Jin et al. [28] presented an error-grating simulation model and recommended various nano-grating strategies, including the use of alternative materials and adjustments to fabrication structural parameters, to enhance the light extraction efficiency of LEDs. They suggested that the incorporation of SiO2 nanorod arrays (NR) was the optimal approach based on a comparison with other materials used as patterned bottom reflection layers in the literature.

Wang et al. [29] proposed the fabrication of a multilayered transparent conductive electrode (TCE) for AlGaN-based UV LEDs, enhancing their optoelectronic properties, with a structure of ITO/Ga2O3/Ag/Ga2O3. This complex TCE exhibited very high transmittance values at 365 nm and extremely low specific contact resistance after annealing. Zhao et al. [15] introduced the concept of using two single ITO layers for GaN-based UV LEDs to improve light extraction efficiency (LEE) and establish low-resistance ohmic contact with the p-GaN layer. This approach was implemented using laser direct writing and supported by numerical simulations. In the final article of the section, Tang et al. [30] described their efforts to enhance LEE in flip-chip (mini) GaN-based LEDs by managing the total internal reflection at the sapphire/air interface through a tetramethylammonium hydroxide (TMAH)-based etching process. In this approach, the device underwent the formation of hierarchical prism-structured sidewalls, strategically designed to enhance light output power by capitalizing on light trapping and scattering phenomena. Moving on to the third section of this Special Issue, we find three novel studies and a review article centered on photodetectors. First, Shih et al. [31] developed both p- and n-type Si heterojunction photodetectors incorporating graphene oxide (GO) with varying oxidation degrees.

They demonstrated that adjusting the oxidation degree, achieved through hydrogen peroxide tuning during the oxidation process, led to enhanced photoresponse in n-type Si heterojunction devices and conversely in p-type devices. Additionally, Xue et al. [17] presented a dual approach involving the controllable synthesis of high-quality 2D perovskite platelets compatible with conventional substrates with a melting point exceeding 100°C and the subsequent fabrication of high-performance photodetectors. Lee et al. [20] reported on the development of an ultrahigh sensitivity CdTe microdots-based photodetector on a bottom bismuth-coated ITO/glass substrate. These devices exhibited exceptional durability and efficiency under stress conditions, primarily attributed to the piezo-phototronic effect, which significantly influenced the height of the Schottky barrier. Concluding this section, Shi et al. [32] presented a comprehensive review summarizing current insights and achievements in the realm of organic photomultiplication photodetectors, highlighting the trap-assisted carrier tunneling effect, while also considering alternative operational mechanisms, future prospects, and challenges.

The fourth section introduces novel contributions related to various dynamic devices, featuring three research articles and a review. Guo et al. [33] successfully manipulated the geometry of GaN-based nanobricks to function as efficient dielectric metasurfaces for simultaneous manipulation of orthogonal linear polarizations in visible light. They also designed a polarization beam splitter (PBS) and the necessary focusing lenses at a wavelength of 530 nm, offering promising options for visible light optical devices. In another simulation study, Ma et al. [34] proposed a metamaterial structure comprising a gold split-ring and a graphene one to enhance the electromagnetically induced transparency (EIT) effect in the mid-infrared (MIR) region. They aimed to create a tunable transparency window by adjusting the coupling distance and/or the Fermi level of the graphene-based split-ring, with potential applications in various light management nanodevices. Wu et al. [35] presented the development of a reusable and flexible tunable filter using advanced electrowetting fluid-manipulation technology. They observed that by adjusting the period of the grating structure filter, they could achieve reflection of CMY (cyan, magenta, yellow) primary colors. Additionally, the device demonstrated significantly shorter response times, attributed to the rapid electrowetting fluid manipulation process. This section concludes with a comprehensive summary of the latest achievements in dynamically tunable metasurface-based applications incorporating liquid crystals (LCs) by Ma et al. [36]. They explore various rational architectures and common factors for adjusting the optical properties of LCs, offering insights into combinations between LCs and a range of metasurfaces to enhance compatibility with high-performance functional dynamic nanodevices.

Finally, the last part of the Special Issue comprises original articles highlighting the realization of other efficient optoelectronic nanodevices, such as field emission (FE) devices and transistors. Stylianakis et al. [14] conducted a comparative study on the FE performance of four solution-processed approaches, including the use of polymeric and fullerene derivatives' composites, to develop rGO-based cold cathodes for FE devices. Their prepared devices exhibited excellent stability, a higher field enhancement factor, and significantly lower turn-on fields compared to reference n+-Si/rGO FE devices. Celebrano et al. [37] concluded the Special Issue by investigating the photocurrent behavior of an erbium-doped and co-doped with oxygen silicon-based transistor at room temperature (RT), examining variations in the laser source wavelength. They observed that photocurrent strongly depended on both the power and frequency of the laser source, highlighting the potential incorporation of Er-doped silicon in RT single photon resonators.

In summary, the Special Issue titled "Optoelectronic Nanodevices" compiles original research contributions from diverse subfields of optoelectronics. This collection showcases outstanding experimental and simulation studies that underscore the potential of novel organic, inorganic, hybrid composites, as well as 2D nanomaterials to enhance the performance and extend the lifetime of conventional optoelectronic applications.

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