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Editorial

Special Issue on Recent Advances and Future Trends in Nanophotonics II

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1. Introduction

Nanophotonics, at the forefront of science and engineering, intrigues researchers across disciplines with its transformative potential for diverse technologies. The Special Issue of *Applied Sciences* titled "Recent Advances and Future Trends in Nanophotonics II" offers a thorough summary of the latest breakthroughs and their impact across various application areas. It covers a broad spectrum of topics, from exploring new directions in nanophotonic science to driving innovation in information processing, communications, biomedical sciences, and imaging and environmental sustainability.

To leverage existing microelectronics technology, silicon (Si) is recognized as the primary material for investigating integrated photonic circuits, driving the increasing interest in silicon-based nanophotonics over recent decades. Fabrication techniques in micro- and nano-silicon photonics enable the cost-effective integration of electronic, photonic, and sensing devices on a single chip. Extensive efforts have been dedicated to developing novel silicon photonic components, resulting in innovative solutions with applications in telecommunications and multichip optical interconnections, promising to enhance the performance of future commercial processors.

2. An Overview of Published Articles

In contribution 1, Kaps and coauthors investigate various strategies employed to improve the in-plane performance of conventional s-SNOM probes. For instance, efforts have been made to optimize the shape of the SFM tip [1] and to tilt the tip cone in relation to the normal sample surface [2]. Additionally, enhancing the sample's in-plane response can be achieved by incorporating dedicated nano-antennas onto the sample surface [3]. Furthermore, both theoretical [4] and experimental [5] evidence has shown that exciting the sample close to its optical resonance yields a notable in-plane signal even with standard s-SNOM tips. This in-plane response is closely linked to resonant excitation, thereby increasing its sensitivity to local sample properties within that frequency range. Consequently, subtle variations in local sample properties, such as mechanical stress [6] and permittivity anisotropies [5,7,8], are anticipated to significantly influence the in-plane contributions in s-SNOM.

In contribution 2, Menahem and Malka highlight how back-reflection poses a significant challenge to the efficacy of transmitter systems, particularly the reflection back into the laser source. In Si-based MMI couplers, reflections may occur due to the self-imaging phenomenon and refractive index mismatches between Si and SiO_2 [9].

Studies indicate that polycarbonate polymer optical fiber can serve as a multiplexer or demultiplexer for RGB signals with insertion losses (ILs) ranging from 0.6 dB to 1.2 dB [10,11]. Additionally, a four-channel demultiplexer operating in the green light spectrum has been realized using a multi-slot waveguide structure based on gallium nitride (GaN) [12]. Furthermore, researchers have successfully divided four [13] and eight [14] channels in the visible and C-band spectrums, respectively, utilizing GaN MMIs. However,

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it is noteworthy that these studies did not consider the back-reflection effect, which is crucial for transmitter functionality [15].

In contribution 3, Hatifi and coauthors investigate fluorophores that find widespread biomedical utility as tracers and markers, such as when linked to DNA strands in devices for virus detection in blood samples. The application of such techniques in lab-on-a-chip setups holds promise [16], especially during pandemics, offering rapid virus detection in airports or other public areas. Additionally, they can serve as markers for verifying the authenticity of certain manufactured goods, thwarting counterfeiting attempts, as proposed here. Fluorimetry boasts rapid response times, sensitivity of excited states to local environments, and the ability to incorporate fluorophores into chips/devices, enabling simultaneous measurement of multiple samples in a short duration [17]. While fluorophores are commonly used for tracing and marking [17,18], operating them in the strong-coupling regime is unusual. Recent advancements have explored strong coupling for potential quantum chip applications, employing fluorophores tethered to oligonucleotide strands and integrated into cavities [19]. These DNA or RNA oligonucleotide strands offer the flexibility to position the probe within the cavity or link it with a plasmonic nanoobject (e.g., a gold nanosphere), akin to an external cavity [20,21]. However, this advantage is counterbalanced by the relatively high design and purification costs associated with oligonucleotides, compounded by aging issues (stability of oligonucleotide probes within the cavity). Contribution 3 introduces a novel fluorescence technique leveraging the intense light–matter interaction of an embedded nanoprobe within a plasmonic cavity. The strong light–matter interactions between nanoprobes and cavity modes typically manifest as changes in the excitation spectrum (electronic or vibrational) of the coupled system [22].

The article by Jia et al. (contribution 4) introduces an innovative design for a surface-enhanced Raman spectroscopy (SERS) substrate, aiming to achieve exceptional sensitivity and rapid, intimate contact between the target structure and the optical hotspots. The proposed substrate offers an enhancement factor of 10^8 or greater, potentially enabling the detection of immunomagnetically densified bacteria. Indeed, rapid detection of bacterial infections is a pressing concern in infectious disease diagnostics and treatment, with sepsis alone claiming over 25 percent of its victims [23]. However, the current clinical standards for sepsis diagnosis can take up to five days to culture and identify bacteria [24].

SERS emerges as a label-free optical biosensing technique, leveraging a modified form of Surface Plasmon Resonance (SPR). In Raman spectroscopy, when laser light interacts with a sample, it undergoes inelastic scattering, resulting in a change in wavelength according to the vibrational modes of the molecules [25]. This shift provides detailed vibrational information about the chemical bonds, offering high spatial resolution [26]. SERS enhances Raman signals using metallic nanomaterials, typically in the form of SERS tags, which consist of modified metallic nanoparticles equipped with specific capturing probes or Raman reporter molecules [27]. This study introduces a new SERS substrate design aimed at achieving high sensitivity and rapid, close contact between the target structure and optical hotspots for immunomagnetic bacteria concentration. The substrate utilizes inverted nanocone structures made of transparent PDMS, guiding light to plasmonic gold nanorods positioned at the top of the cones. With a highly reflective and low-loss outer layer, photons undergo multiple reflections, significantly increasing photon density at hotspots, potentially enabling the detection of immunomagnetically densified bacteria.

Finally, contribution 5 is an interesting review by Piergentili et al. on quantum information with integrated photonics. Authors highlight how the ongoing challenge revolves around establishing a scalable and convenient platform for the practical implementation of quantum technologies, which encompass protocols and devices capable of computations significantly faster than their classical counterparts. IBM [28] and Google [29] have recently developed prototypes of commercial quantum computers utilizing superconducting qubits through the superposition of supercurrents in Josephson junctions, requiring extremely low temperatures for operation. Additionally, research has explored superconducting opto-electronic circuits integrated with photonic components for rapid, energy-efficient computation [30], photon detection [31], and polarization-sensitive imaging [32,33]. However, for these new quantum technologies to be seamlessly integrable into existing systems and infrastructures developed for digital and telecom information technologies, there is a growing emphasis on the development of integrated photonics chips in silicon for the generation, modulation, and detection of light [34,35].

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