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Flexible, Wearable and Stretchable Photonics: feature issue introduction

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Abstract: We introduce the feature issue of *Optical Materials Express* on flexible, wearable and stretchable photonics. This collection highlights recent advances in the design, fabrication, and application of compliant photonic systems, spanning topics from stabilizing flexible chalcogenide photonics and textile-based conformal SERS sensors to light-driven soft actuators, self-written optical interconnects, and miniaturized implants for biomedical interfaces.

1. Introduction

Integrating photonics with dynamic, non-planar, and biological environments necessitates a departure from traditional rigid platforms toward systems that are inherently flexible, stretchable, and compliant [1,2]. Such a transition is not merely a change in substrate but demands concurrent innovation across materials, fabrication processes, and device architectures to maintain optical performance and reliability under mechanical deformation. This feature issue brings together eight articles that exemplify this multidisciplinary endeavor, addressing core challenges from foundational materials to integrated systems for sensing, actuation, and biomedical intervention.

2. Feature issue overview

2.1. *Material innovations for compliant platforms*

The realization of high-performance soft photonics begins with the development of enabling materials. Two contributions herein address this foundational layer. First, the work by Kim et al. provides a comprehensive review of intrinsically stretchable and transparent conductors, a critical component for soft optoelectronics [2]. It systematically analyzes the trade-offs between conductivity, transparency, mechanical stretchability, and environmental stability in both metal-based and conductive polymer systems, outlining the material selection landscape for integrated wearable and implantable devices.

Second, long-term reliability of the photonic components themselves is paramount. Wu et al. present a quantitative analysis of chalcogenide glass aging on flexible substrates [1]. Their study demonstrates that controlled thermal annealing can accelerate the structural relaxation of Ge-Sb-Se glasses, significantly reducing the temporal drift of resonant wavelengths and pushing the devices toward a stable operating state faster. This finding offers a crucial processing strategy

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to enhance the longevity and predictability of high-index-flexible waveguide circuits for sensing applications.

2.2. Fabrication and integration for complex systems

Moving from materials to functional modules, advanced fabrication techniques enable complex system integration. Stührenberg et al. detail a multichannel flexible waveguide module with single-lens coupling to a laser diode array [3]. This work showcases a precision alignment and packaging strategy to create a miniaturized, chronically implantable device for optogenetic stimulation. The module's ability to maintain stable optical output over extended periods highlights the convergence of optical design, flexible photonics, and biomedical engineering.

To create optical interconnects in dynamic settings, Futawatari et al. introduce a method for the integrated fabrication of flexible light-induced optical waveguides with cladding via selective polymerization [4]. This technique allows for the "self-writing" of optical "solder" between components, offering improved misalignment tolerance and a promising route toward reconfigurable optical links in moving systems, such as autonomous vehicles.

2.3. Functional devices for sensing and actuation

Das et al. develop fabric SERS sensor chips based on Ag nanowires grown on large-area woven textiles [5]. This approach transforms ordinary textiles into highly sensitive, biochemical sensors, enabling label-free detection and paving the way for wearable diagnostic platforms.

Another sensing modality is demonstrated by Biswas et al., who report self-assembled metal-elastomer wrinkles for reversible coloration and curvature sensing [6]. Their one-step process creates mechanically tunable diffraction gratings in which structural color changes reversibly with surface curvature. This provides a simple yet robust optical mechanism for visual strain mapping in wearables or soft robotics.

In actuation, Zhen et al. present a waveguide photoactuator-enabled underwater microgripper [7]. By addressing heat dissipation in water with innovative insulation, they enable effective photothermal bending actuation in aqueous environments. This work extends the realm of opto-mechanical control to underwater biomedicine and micromanipulation.

2.4. Toward wearable clinical diagnostics

Extending photonic functionality to direct clinical impact, Taccheo et al. outline a pathway to versatile, point-of-care, and wearable photonics in the mid-infrared and fingerprint region [8]. Their invited perspective discusses the integration of quantum cascade lasers, advanced waveguides, and photoacoustic detection to overcome challenges in tissue probing and signal analysis, charting a course for non-invasive, wearable devices capable of monitoring key physiological biomarkers.

3. Conclusion

The works assembled in this issue reflect the vibrant and multidimensional progress in flexible photonics. From conquering material-level challenges of conductivity and stability, to mastering integration for implants and dynamic interconnects, and finally to demonstrating novel sensors, actuators, and diagnostic pathways. Each contribution expands the functional horizon of what photonic systems can achieve when liberated from rigid confines.

The trajectory points toward greater integration of these capabilities: integrating sensing, actuation, and communication on a single, compliant substrate to create intelligent, adaptive systems. As the material and device innovations highlighted here mature, they will further blur the line between photonic tools and their applications in healthcare, human-computer interaction, and environmental monitoring.

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