

Preface

Since its discovery, the fiber optics field has undergone a tremendous growth and advancement over the past several decades. As optical fibers cemented their position in the telecommunications industry and its commercial markets matured, parallel efforts were carried out by a number of different research groups around the world to exploit them also in the sensors field. Nowadays, a variety of commercial fiber optic sensors have widespread use for structural sensing and monitoring applications in civil engineering, aerospace, marine, oil and gas, smart structures, and bio-medical devices, to name a few.

Although fiber optic sensors have, in many cases, completely replaced and outperformed their counterparts based on more conventional technologies, it is out of the question that optical fibers are still mainly conceived as communication medium. So far, the fiber optic industry focused its efforts on the development of devices and components whose functionalities are mainly related to the silica glass properties. For this reason, in the development of photonic systems both for communication and sensing applications, several out-of-fiber optical components, ranging from light sources, modulators, polarizers, up to photo-detectors, are currently employed. This is why there is currently an increasing market demand for highly integrated and multifunctional devices with advanced performances and unrivaled features. A significant technological breakthrough would be the development of these components and devices “all in fiber” through the integration of advanced functional materials at micro and nanoscale. All the above considerations lead to envision the “Lab-on-Fiber” concept as a concrete technological solution to actual market demand.

In this context, the “Lab-on-Fiber” technology is an emerging research field which envisions a novel class of advanced and multifunctional photonic devices and components arising from the integration onto optical fibers of different materials at micro and nanoscale with suitable physical, chemical, and biological properties. This fascinating and intriguing research topic is essentially aimed at the development of novel technological platforms where functionalized materials, devices, and components are constructed, embedded all together in a single optical fiber providing the necessary physical connections and light–matter interaction, usefully exploitable and useful in many strategic sectors such as optical processing, environment, life science, safety, and security. The addition of new features and functionalities to optical fibers involves the concurrent approach of different

disciplines ranging from nanotechnology to photonics engineering passing through material science.

This technological innovation is opening the way for the creation of fiber-based multifunction sensing and actuating systems, with enhanced performances and functionalities with respect to conventional technologies. For example, novel fiber optic nanoprobe could be judiciously integrated with microfluidics components to provide new Lab-on-chip implementations, taking advantage from the easier connection of the optical chain to complex lighting systems as well as sophisticated remote interrogation units.

“Lab-on-Fiber Technology” is becoming a key and enabling technology behind many devices, components, and systems found in the modern home, factory, and research lab as well as in many strategic industrial sectors. The enormous potentialities of this new intriguing technological world could envisage a primary role in what we can safely label as the “Photonic Century,” especially if main issues, concerning the identification and definition of viable fabrication methodologies, routes, and strategies, enabling the integration of a large set of materials onto non-conventional substrates as the case of optical fibers are judiciously addressed.

Many research efforts have been carried out aimed to translate the vision in a technological reality, and according to the methodologies proposed so far, the book has been divided into the following sections, comprising a series of commissioned chapters from leading experts in the Lab-on-fiber technology field:

Section 1: The *macro to micro/nano approach*, enabling the thermal scaling of a macroscopic pre-form down to the microscopic and nanoscopic scale, by means of the fiber drawing technique.

In this context, Chap. 1 provides an overview of multimaterial fibers, starting from a discussion on material constraints, fiber drawing, and pre-form fabrication up to the introduction of photonic and optoelectronic multimaterial fibers with novel optical and sophisticated electronics. The fabrication and the applications of optical microfibers and nanofibers, i.e., optical fibers with diameters close to or smaller than the wavelength of the guided light, are presented in Chap. 2 as a valuable technological platform for Lab-on-Fiber with strong near-field interaction.

Section 2: The *transferring method*, essentially consisting of the previous fabrication of dielectric and metallic structures onto planar substrates (by using standard nanofabrication techniques) followed by their successive transfer onto optical fiber substrates.

By following this approach, with the aim of combining the good performances of photonic biosensors on chip with the advantages offered by optical fibers, in Chap. 3 an optical fiber probe for label-free biosensing is presented, based on a high Q silicon-on-insulator ring resonators transferred on the fiber tip. Similarly, Chap. 4 deals with a fiber device for both refractive index and temperature measurements based on the integration of a photonic crystal slab fabricated on standard Si wafers and transferred onto optical fiber facet. In addition to the transferring of silicon membranes, both hybrid and double transfer UV-curing

nanoimprint-soft lithography techniques (discussed in Chap. 5) enable pattern transfer on highly curved surfaces (e.g., the sidewall of an optical fiber) with a resolution down to a few nanometers. In the same line of argument, Chap. 6 discusses the fabrication strategies to apply on the fiber tip a flexible, ultrathin polymeric membrane supporting metallic nano-features, which acts as a guided mode resonance filter.

Section 3: The *direct-writing method*, relying on the use of nanofabrication techniques suitably adapted to directly operate on the optical fiber. Both top-down, using Electron-Beam Lithography (EBL) or Focused-Ion Beam (FIB), and bottom-up approaches, by means of self-assembly, have been so far demonstrated.

In Chap. 7, a fabrication process involving EBL on the optical fiber tip is discussed, for creating multifunctional optical probes for both label-free chemical and acoustic sensing. By using FIB milling and two-photon lithography techniques, the realization of single-fiber optical tweezers able to create a purely optical three-dimensional trap is provided in Chap. 8.

The FIB milling technique is also demonstrated in Chap. 9 to enable the development of innovative fiber optic hydrogen sensors based on C-shaped nano-apertures patterned onto the tip of a Pd coated fiber.

By using bottom-up self-assembly approaches, as discussed in Chap. 10, it has been shown that 2-D structures made of metallic nanoparticles can be coated on D-shaped fibers. Moreover, a fabrication process based on the so-called “breath-figure technique” can be exploited to realize metallo-dielectric crystals onto optical fiber tip, as presented in Chap. 11.

Section 4: *Integration of functional materials onto conventional and unconventional optical fibers*, opening up interesting possibilities for adding new functionalities and developing advanced optical fiber probes for sensing applications.

For example, techniques for manipulating liquids on micro- and nanoscale are presented in Chap. 12, providing possibility of functionalizing sensing area of lab-in-fiber devices. Chapter 13 deals with the integration of optical fibers with different types of nanoscale structured materials (such as multilayer-based nano-structures, sol-gel-derived materials, molecularly imprinted polymers, and metallic thin films and nanoparticles) that so far significantly contributed to give a push to the continuous development of new fiber optic sensors.

The biological functionalization of grating-based fiber optic transducers by means of T4 bacteriophages, enabling the realization of a label-free biosensor for the detection of *E. coli*, is discussed in Chap. 14. Concerning unconventional optical fibers, Chap. 15 reviews the state-of-the-art advances of photonic crystal fibers as inherent lab-in-fiber optofluidics platforms (thanks to the easy access of the fiber air channels for surface functionalization) for monitoring important chemical and biological events. Finally, Chap. 16 provides an overview of micro- and nano-structured optical fiber sensors, directly associated with surface plasmon resonance sensing.

The book thus highlights the main achievements of the Lab-on-Fiber technology roadmap, providing an exhaustive overview of the main fabrication

approaches including first demonstrations of optical devices and components and their use in practical applications. The text aims to make the readers aware of the enormous opportunities offered by this innovative technology that is leading it to be one of the hottest topics in the photonics community. As this topic is still a subject of dynamic research, this book can represent a reference and at the same time a source of inspiration for new ideas and concepts.

In conclusion, the editors hope that this book, reflecting ongoing and latest research advances in this promising area, could bring readers with very broad competencies ranging from chemistry, biology, electronics, photonics, material science, nanotechnologies, and other disciplines to seek and promote multidisciplinary and synergic cooperations for reaching further innovations in this area.

Benevento, Italy

Andrea Cusano
Marco Consales
Alessio Crescitelli
Armando Ricciardi

Lab-on-Fiber Technology

Cusano, A.; Consales, M.; Crescitelli, A.; Ricciardi, A.
(Eds.)

2015, XXII, 359 p. 213 illus., 184 illus. in color.,
Hardcover

ISBN: 978-3-319-06997-5