

ABSTRACT

The development of modern fiber-optic systems increasingly requires local modification of fiber geometry after the fabrication process. This is particularly challenging in microstructured and hollow-core fibers, where the small dimensions of the internal features, curved outer surface, and presence of thin-walled capillaries significantly limit the applicability of conventional machining techniques. The main objective of this dissertation was to develop a repeatable methodology for the controlled micromachining of such structures while preserving their geometrical integrity and optical functionality. Two subtractive processing technologies were investigated in detail: focused ion beam (FIB) machining and ultrashort-pulse femtosecond laser ablation.

Particular attention was devoted to FIB technology, including both the physical mechanisms of ion-matter interaction in dielectric materials and the practical aspects of sample positioning, beam parameter selection, scan strategy, and mitigation of charging and redeposition effects. The use of a xenon plasma ion source enabled the precise and repeatable fabrication of microchannels in complex fiber structures, followed by their direct verification using electron microscopy and cross-sectional analysis. In parallel, femtosecond laser micromachining procedures were developed for wavelengths of 1030 nm and 343 nm. The results demonstrated that the two technologies exhibit fundamentally different characteristics and should be regarded as complementary rather than interchangeable. FIB provides the highest level of geometrical control and structure quality, whereas femtosecond laser processing offers substantially higher processing speed and potentially easier scalability to the removal of larger material volumes.

The ability of the developed methods to introduce new functionality into an optical fiber was verified using an antiresonant hollow-core fiber (ARHCF) designed for spectroscopic gas detection. Side microchannels were fabricated through the fiber cladding to provide direct access from the external environment to the hollow core while preserving the geometry of the thin-walled antiresonant elements. In the demonstrated configuration, these microchannels did not merely serve to accelerate fiber filling, but constituted the primary route for delivering the analyzed medium into the hollow core of a probe with a sealed end face and a micromirror positioned inside the fiber. Measurements performed using second-harmonic wavelength modulation spectroscopy (2f-WMS) in the near- and mid-infrared spectral ranges confirmed that the modified structure could be successfully used for methane detection.

The results demonstrate that controlled micromachining can be used not only to locally modify the geometry of optical fibers, but also to create functional configurations that are inaccessible in unmodified structures. The developed FIB and femtosecond laser processing procedures therefore constitute a complementary set of tools for the microstructuring of complex glass components, while their implementation in ARHCFs confirms the potential of these technologies for the development of miniaturized photonic and sensing systems.