Abstract

Currently optical fibres are widely used for telecommunications and sensing applications due to their immunity to electromagnetic fields, and their light weight and small design. In particular for sensing purposes, different types of specialised fibres have been development either with special designs, such as microstructure patterns or using different kinds of materials. In this way, the sensitivity of the fibres can be enhanced or become unresponsive to specific parameters. However, not all the speciality fibres are photosensitive and efficiently processed with conventional UV lasers to manufacture sensing structures; as a result, most of the 'alternative' material or designs fibres are not fully exploited.

On the other hand, the femtosecond lasers modify materials using a different principle. The material photosensitivity is not required to induce refractive index changes in the fibres, indeed minimising linear absorption is desirable and the greater the transparency of the material the better for femtosecond laser processing. In this case it is multi-photon absorption that occurs at the laser focus that is important for laser-induced material modifications. In this thesis, we present the development and manufacturing of advanced fibre optic sensors using a femtosecond laser operating at 517 nm. A wide range of different optical fibres processed allows for the fabrication of not only fibre Bragg grating (FBG) sensors but also chirped gratings, Fabry-Perot cavities, and Mach-Zehnder interferometers (MZIs).

I summarise several examples that a unique to femtosecond laser inscription. The precise and accurate control of the inscription parameters during the fabrication of sensors in a multi-mode optical fibre can lead to control of the coupling between a Bragg grating and the higher order modes of a low loss polymer optical fibre (POF). A result is that we are able to inscribe single-peak FBG sensors as an array in the multi-mode optical fibre. We demonstrate this by inscribing FBGs in a low loss POF, in which it is not possible to inscribe gratings using conventional UV-laser sources, and hence demonstrate applications using polymer fibres over several tens of meters, which exceed the operating length of POF-based sensors by three orders of magnitude at an operating wavelength of 1550 nm.

We show the inscription of FBGs in conventional silica fibre inscribed and characterised by exposing the fibre to different femtosecond laser pulse conditions, whereas interferometric structures, such as Fabry-Perot cavities, MZIs, and waveguide Bragg gratings were written using similar inscription parameters, producing compound optical sensors that are able to sense properties such as curvature and refractive index. Moreover, traditional methods for detecting refractive index changes, such as tilted-FBGs, were further studied and for which we developed a flexible inscription method that allowed for the selective control of the range and position of radiation and cladding modes across the wavelength spectrum, applied to refractive index sensing.

We explored other fibre materials, such as phosphate fibres for bio-sensing applications that were laser-processed for the inscription of different structures (FBGs, Fabry-Perot cavities, chirped gratings) and characterised under different conditions (temperature and humidity). Finally, an important step was made in the processing of novel fibres such as silicon-core/glass cladding fibre, and polymer fibres with unique mechanical characteristics, which were processed and characterised showing their sensing superiority compared with other optical sensors.

The content of this thesis contains several novel pieces of research in the field of optical fibre sensing, and femtosecond laser processing of optical fibres that contribute to the better understanding of how one should process different optical fibre materials, with a focus on the difficulties and obstacles that were faced. In conclusion, new routes for industrial processing of materials are enhanced and motivated by the results of this thesis.

Keywords: Femtosecond Laser, Fibre Bragg Gratings, Polymer Fibres, Waveguides, Optical Fibre Sensing