Study and development of femtosecond pulses laser-produced Bragg grating sensors in bulk silica: Applications to instrumented compliant mechanisms.

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This PhD thesis, conducted in co-tutelle between the Université de Mons and the Université Libre de Bruxelles in Belgium has focused on the study and development of waveguides and Bragg gratings in pure silica planar substrates entirely relying on a femtosecond pulses laser process.

The inception of femtosecond laser pulses dates back to 1985 when Gerard Mourou and his team first observed their interactions with fibres. Since then, femtosecond lasers have emerged as a pivotal technology due to their unique precision, resolution, and capability to directly alter surfaces for creating micro-structures or optical configurations. The considerable advancements obtained in this ever growing field over the past decades has led to the development of a commercial device known as the Femtoprint machine, which integrates a femtosecond pulses laser focused through a microscope objective, a 3D axis moving plate boasting high resolution in the positioning and a computer-aided design software that drives the whole system.

Through refined studies and analyses in an optimization process, we have investigated the impacts of different parameters (pulse energy, repetition rate, writing speed, polarization) of the Femtoprint process on the quality of engineered structures. Our primary research objective was to fabricate an optical waveguide encompassing a uniform Bragg grating within a flexible structure entirely engineered in a fused silica glass substrate. We had also to fabricate an optimized cavity to enable a good optical connexion between the femtosecond pulses laser-engineered waveguide and a connecting single-mode optical fibre. To achieve this, we conducted a thorough examination of all available parameters and assessed their suitability for the desired surface modifications. For quality characterization purposes, we employed methodologies including Digital Holographic Microscope (DHM) analysis, polarization-based amplitude spectral measurements and infrared camera imaging.

The in-built Bragg gratings were then characterized for sensing purposes. The impact of a temperature change from room temperature to ~140 °C was first investigated. Then, mechanical characterizations were performed. Experimental set-ups have been progressively built and optimized to apply controlled axial strain, 3-point bending and flexure (cantilever beam) on the produced sensing platforms. Experimental sensitivities were determined in each case, with a good adequation with the expected values from the literature review. Some gratings were also produced close to the edge of the substrate, with the ambition to measure changes in the surrounding refractive index value.

This work opens doors for the advancement of sophisticated instrumentation, not only in fields like photonics and optomechanics but also in domains such as biomedical engineering and environmental monitoring. Furthermore, beyond their sensing capabilities, these monolithic structures showcase exceptional mechanical, thermal, and optical properties intrinsic to fused silica glass. This distinctive properties put them as optimal candidates for diverse applications, including precision instrumentation in demanding environments. Their capability to endure harsh conditions with high sensitivity and accuracy renders them interesting instruments for the future.