Advanced fiber Bragg grating sensors for high temperature sensing

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Abstract

High-temperature resistant fiber Bragg gratings-based sensors have attracted significant attention in recent decades for many applications in harsh environments due to their outstanding features. Uniform and tilted fiber Bragg gratings (FBGs/TFBGs) are used for multi-parameter and quasi-distributed sensing to monitor different parameters such as strain, temperature, humidity, bending, pressure, external refractive index. For temperature sensing, UV photo-inscribed gratings (Type I) only sustains up to 300 °C without degradation in reflectivity for a short time application. Higher temperature causes a thermally induced decay in the reflectivity of gratings or completely erases the grating. Therefore, preserving the grating integrity in a harsh environment is challenging and important for many applications in research and industries.

This PhD research aims to study the regeneration process in Type I FBGs and TFBGs and to improve the state of the art of high-temperature-resistant grating-based sensors through experimental characterization of FBGs and TFBGs. The regenerated grating retains the best features of seed gratings and can operate at high temperatures up to 1000 °C. Since TFBG is a young technology and there are few studies on high-temperature behavior and the regeneration process, the ultimate goal of this PhD is to regenerate TFBGs and enhance their regeneration efficiency for the cladding modes.

The thermal regeneration process is a complex process that depends on various parameters. We studied the regeneration process by investigating the effect of the inscription laser types and wavelengths (Excimer laser 193 nm, femtosecond laser 266 nm), the thermal profiles (isothermal, isochronal heating), the heating ramp rates, the target temperatures (between 500 °C and 1000 °C). We demonstrated that efficient regeneration depends on the thermal profile, heating rate, and target temperature, whereas the laser type and wavelength have no significant effect on the regeneration efficiency.

We showed that the regeneration efficiency of TFBGs is smaller than FBGs and does not depend on the tilt angle. Besides, we demonstrated that the regeneration process depends on the fiber composition by comparing the regeneration process of gratings inscribed in single-mode H_2-loaded photosensitive B/Ge co-doped fiber (PS-1250/1500) and in single-mode H_2-loaded standard telecommunication silica fiber (SMF-28). PS-FBGs are regenerated with a stronger efficiency than SMF-FBGs, whereas the regeneration efficiency in SMF-TFBGs was stronger than PS-TFBGs.

Furthermore, the sensitivity of SMF-TFBGs and regenerated SMF-TFBGs (RTFBGs) to the surrounding refractive index (SRI) changes were measured, and the results showed that the SRI sensitivity of RTFBGs is comparable with TFBGs, and the regeneration process does not change the grating geometry.

Moreover, in this PhD, we applied the design of the experiment (DoE) approach to study FBG sensing and regeneration efficiency. DoE is a structured and organized way of operating and analyzing experiments to evaluate the factors that affect the response. DoE gives maximum information of experiment with the minimum number of the runs. The first-order model with interaction of a two-level factorial design was used to study and conduct investigations of two and three factors for temperature, humidity, and strain sensing. The results of DoE for FBG sensing agreed with the classical approach of measurement while giving access to the interaction sensitivity between the factors. We showed the effect of temperature and strain on the humidity sensing of a Polyimide coated FBG humidity sensor and the significance of calibration. Then, we designed experiments to investigate the effect of three factors in the regeneration process, including the heating rate, the grating length, and the number of UV pulses used to inscribe the seed gratings. We showed that these parameters interact together in a non-linear way. Therefore, the first-order model with interaction is not sufficient. Nevertheless, by using the classical experimental approach, we found that increasing the grating length and decreasing the heating rate increases the regeneration efficiency, whereas increasing the UV pulses number has a saturation behavior in the seed reflectivity and the reflectivity of RFBGs.

Keywords: Fiber optics, Fiber Bragg grating (FBG), Tilted fiber Bragg grating (TFBG), High-temperature sensing, Design of experiment (DoE).