Contribution ID: **221** Type: **Oral Presentation**

#10-221 Study of fs-void Bragg Gratings in radiation sensitive fibers for radiation measurement purposes

Thursday, June 12, 2025 12:20 PM (20 minutes)

Fiber Bragg Gratings (FBGs) offer significant advantages for monitoring harsh environments, particularly within nuclear facilities. Their compact size, immunity to electromagnetic interference and their large variety of radiation responses, enable accurate, real-time monitoring of temperature, strain and/or radiation levels, providing reliable data with high detection sensitivity. These characteristics make FBGs appealing for ensuring safety and operational control in radiative environments.

This study focuses on the development of type-III FBGs inscribed in highly radiation sensitive fibers using femtosecond laser technology. This process creates periodic voids within the fiber core, which leads to an optical cut-band filter in transmission and an optical pass-band filter in reflection. The peak reflectivity is located at the Bragg wavelength. Changes in void periodicity or effective refractive index both result in a shift of the Bragg wavelength. By exposing these FBGs to X-rays while monitoring temperature, we leverage the Radiation-Induced Bragg Wavelength Shift (RI-BWS) for accurate radiation dose measurements.

The study further compares the Bragg wavelength shift due to X-rays in extreme radiation sensitive fibers (Phosphorus (P)-doped, Aluminum (Al)-doped and Phosphorus/Cerium (P/Ce) co-doped) in comparison with a conventional telecom-grade optical fiber (e.g. SMF-28, 5 wt% Germanium-doped) used as reference. Type-III FBGs inscribed in fibers with different dopants (P, Al, P/Ce, Ge) were studied under irradiation at room temperature. The different fibers were tested in an X-ray irradiation chamber at dose rates of 1 Gy(SiO2)/s and 10 Gy/s up to doses exceeding 50 kGy. Due to their high sensitivity to radiation, only 5 cm of uncoated radiation sensitive fibers were irradiated, the samples were spliced to conventional fibers.

Our results show that RI-BWS follows an exponential trend for the first 50 kGy of irradiation dose. The levels of those shift are of around 25 pm, 41 pm, 65 pm and 12 pm –which correspond to equivalent errors of 2.2℃, 3.6℃, 5.8℃ and 1.1℃ for FBGs inscribed in P-doped fibers, P/Ce co-doped, Al-doped fibers and Ge-doped fibers respectively. P and P/Ce-co-doped fibers then exhibit a linear grow of RI-BWS while the RI-BWS of Al and Ge-doped fibers both reach a plateau. This behavior aligns with Radiation-Induced Attenuation (RIA) behavior in the same fibers. Additionally, the Phosphorus-doped fibers demonstrated strong potential as a dosimeter, since for doses higher than 50 kGy, the Bragg wavelength shifts almost linearly with dose (0.06 pm/kGy and 0.18 pm/kGy for FBGs in respectively P and P/Ce fibers). The grating response in such fiber was studied in terms of detection limit, resolution, and saturation by exposing the fiber to an integrated dose exceeding 2 MGy.

The lowest detection limit was about 1 pm set by the measurement systems (Luna Hyperion, Si-255) and the uncertainties are due to the Bragg peak detection.

We also investigated the grating behavior in Phosphorus-doped and Germanium-doped fibers, under combined high temperature (at 280℃) and X-ray irradiation (10 Gy(SiO2/s –100 kGy). Under these conditions of radiation and temperature, it turns out that Bragg grating response is independent of fiber composition, with a RI-BWS near zero (± 10 pm or less than a degree Celsius and ± 20 pm errors or 1.8℃ respectively for P-doped and Ge-doped fiber Bragg gratings). These uncertainties are due to the temperature variations of the heating plate.

Further research studies are set to explore the use of those fibers and dopants combined with Type-III FBGs as sensors in challenging high temperature and radiation environments as well as combined neutron and gamma radiation. The low detection limits are to be studied by testing the response with dose rates lowered by several decades for use in dismantling for example.

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Session Classification: #10 - Current Trends in Development of Radiation Detectors

Track Classification: 10 Current Trends in Development of Radiation Detectors