Active Irradiation Testing of Temperature Sensing Capability of Clad Sapphire Optical Fibers With Type 2 Bragg Gratings Using Optical Backscatter Reflectometry

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This work investigated the temperature-sensing capabilities of Type II fiber Bragg gratings (FBGs) inscribed in sapphire optical fiber in The Ohio State University Research Reactor (OSURR) (Figure 1). A Luna Innovations 4600 optical backscatter reflectometer (OBR) was used to interrogate FBGs in three sapphire optical fibers with an internal cladding that was developed by Ohio State [1]. The sapphire fibers were fusion-spliced to silica lead fibers. In addition to the sapphire fibers, two silica fibers with the same Type II FBGs were included in the experiment as a reference. The fiber-based sensors were irradiated in the Central Irradiation Facility (CIF) of the OSURR for a total of 40 hours over five days at a reactor power of 450 kW, resulting in a total neutron fluence of approximately 2.5×10^{18} n/cm^2 and a gamma dose of approximately 3.48 Grad. Two K-type thermocouples were included within the rig: one at the core centerline and the other 12 inches above the top of the core. The temperature was not actively controlled, but the thermocouples were used to provide a reference to which the fiber-based temperature measurements could be compared.

Results

The FBGs located closest to the silica-to-sapphire fiber splices generally performed much better than the FBGs located further from the splice. All measurements for FBGs located more than ~5–10 cm from the silica-to-sapphire splice either failed or showed prohibitive noise, perhaps indicating that the cladding of the sapphire fiber was not effective in achieving single-mode operation. However, for two of the three sapphire fibers, the FBG located closest to the silica-to-sapphire splice performed well, with the magnitude and time response of the fiber-optic measurements generally matching those of the thermocouples for all five days of irradiation (Figure 2). Some of the observed differences between the various sapphire fibers could be attributed to pre-irradiation heat treatment. The two sapphire fibers that showed better performance were heat treated at >1300°C prior to irradiation while the remaining fiber was heat-treated at 1000°C. The thermal annealing of the clad optical fiber may have a significant effect on transmission in the fiber, due to the creation of nanovoids [2]. The FBGs inscribed in the silica fibers showed no significant noise or signal drift over five days of irradiation, indicating that the Type II gratings themselves perform well under irradiation.

Conclusion

This work showed that temperature sensing using FBGs in sapphire optical fiber is possible given that at least one FBG in two of the three sapphire fibers survived and gave reliable readings up to a total neutron fluence of approximately 2.5×10^{18} n/cm^2. There is still a need to reduce the modal volume and the intrinsic attenuation in the sapphire fibers. However, if these challenges can be overcome, the high melting temperature of sapphire (>2000°C) makes sapphire optical-fiber sensors a potential candidate for monitoring of centerline temperatures during irradiation testing of advanced fuels for high-temperature

Figure 1. Experiment installed in the central irradiation facility of The Ohio State University Research Reactor.

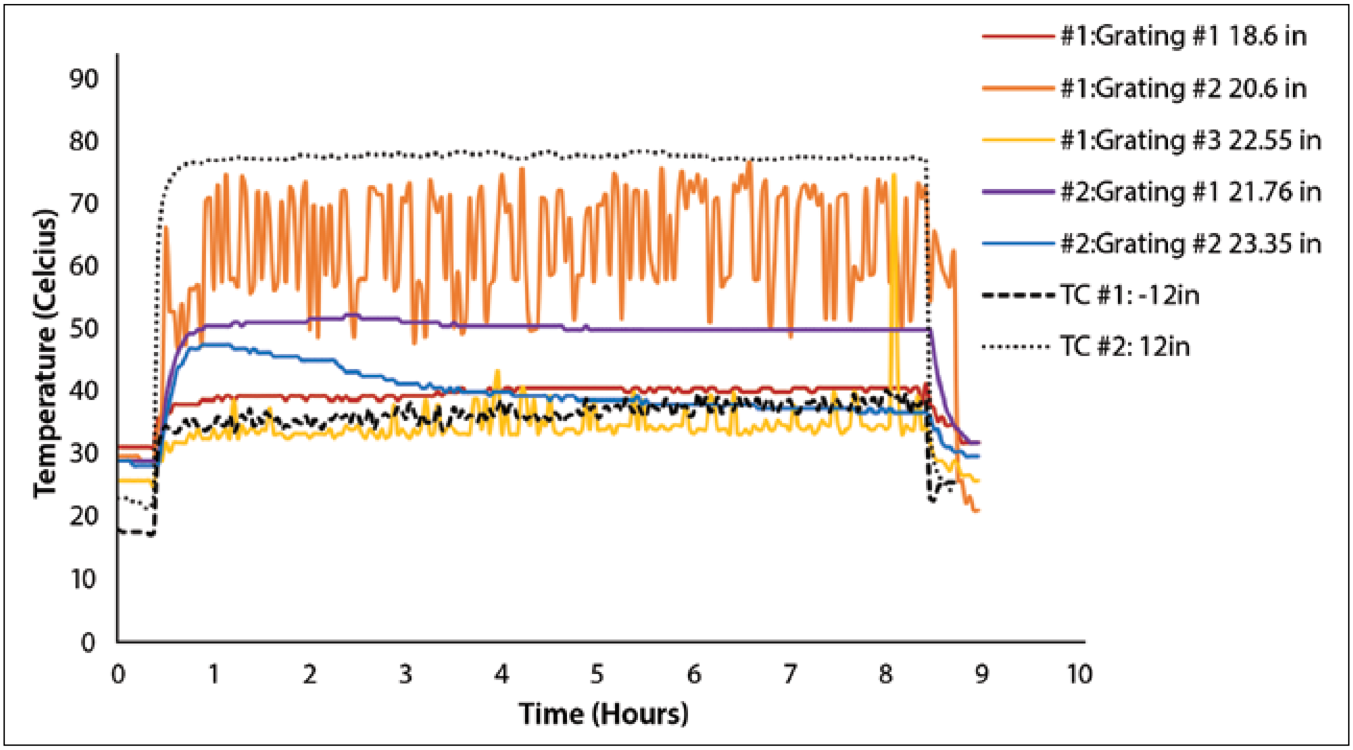

Figure 2. Temperatures measured by FBGs in sapphire Fibers 1 and 2, as well as thermocouples as a function of time on the fifth day of irradiation. Measurements were made at various distances below the top of the OSURR core, with the reactor midplane located 12 inches below the top of the core.

"Modeling of the Creation of an Internal Cladding in Sapphire Optical Fiber Using the $^{6}Li(n,\alpha)^{3}H$ Reaction," in Journal of Lightwave Technology, vol. 36, no. 23, pp. 5381-5387, 1 Dec.1, 2018.

Publications

[1.] K.M. McCary, B.A. Wilson, J.E. Daw, P. Calderoni, C. Petrie, T.E. Blue, "In-Pile OFDR Sensing with Fiber Bragg Gratings in Sapphire Optical Fiber," American Nuclear Society Winter Meeting, Washington D.C. (2019), p. 159-163.

[2.] K.M. McCary, B.A. Wilson, A.H. Birri, T.E. Blue, and C. Petrie, "Suitability of Type-II Fiber Bragg Gratings in Silica Optical Fiber for Temperature Sensing in TREAT," Nuclear Power Instrumentation, Control, and Human Machine Interface Technologies, Orlando, FL (2019), p. 469-477.

Distributed Partnership at a Glance	
NSUF and Partners	**Facilities and Capabilities**
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