Abstract

Civil structures such as buildings, bridges, pipelines, dams, underground tunnels, and mining infrastructures are susceptible to structural damage, with cracks and fractures posing significant threats to both their integrity and human safety. Additionally, high temperatures in workplaces like underground mines or remote areas with heavy machinery induce dehydration, fatigue, and decreased cognitive function, leading to reduced productivity and economic loss. Traditional electrical sensors used to monitor cracks and temperatures in these remote structures can cause sparks during accidents, potentially igniting hazardous and combustible gases and leading to explosions. Fiber-based optical sensors, such as fiber Bragg gratings, are used to monitor cracks and temperatures but suffer from low spatial range and high maintenance costs. The thesis presents the development of innovative optical crack and temperature monitoring sensors. Flexible stress birefringent polydimethylsiloxane (PDMS) membranes were used for crack monitoring. The relative stress in these stretched PDMS membranes was characterized using polarization and interferometric methods. In rectangular membranes, stress was concentrated at the static edge, while in wedge-shaped and bowtie-shaped membranes, stress was concentrated at narrower widths. A 5 mm stretched wedge-shaped PDMS membrane with periodic patterns was used to produce chirped grating patterns on TiO_2 sol coated glass slide using soft lithography technique. These TiO_2 gratings were stacked side by side to construct a crack monitoring device which works on the principle of optical diffraction and has a resolution of 65 μm and a range of 5.8 cm. For temperature monitoring, sol-gel fabricated photonic crystals and holographic structures were used. The temperature response of these quarter-wave thick stacked layered samples was studied towards the development of intrinsic and extrinsic temperature sensors. The spectral shifts of the photonic stop-band and optical Tamm states in metal-coated photonic crystal structures were used as tools to monitor temperature variations. Holographic photonic crystals with different photonic bandgaps were used to fabricate optical fiber-based distributed temperature sensors. The sensitivity exhibited varies from 0.61 nm/°C to 0.95 nm/°C respectively. Finally, efforts were made to bring-in optical solutions towards problems involved with electrical illumination in oxygen-rich and combustible gas environments, like underground mines, wherein sparks can lead to explosions. For such ambient conditions, proper testing and certification are required for installing electrical luminaires. An alternative approach comprising of optical fiber-based solar illumination with simultaneous communication inside mines was demonstrated. Sunlight was coupled into a 400 μm dia optical fiber using a lab-built solar tracker for daytime illumination. Solar panels were used to charge batteries to power lasers for hybrid illumination at night and during cloudy days. Using rhodamine-doped TiO_2 diffusers, 60 lux illumination of yellow light at the work plane was achieved. Light-based light-fidelity (Li-Fi) communication was also demonstrated alongside illumination.

Keywords: Crack monitoring sensor, Chirped grating, Temperature sensor, Photonic crystal, Holographic photonic crystal, One-dimensional photonic crystal, Optical Tamm states, Solar illumination.