Honors Capstone Research (HCR) Summer 2021 Program Proposal

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Concentration: Optics and Photonics Technology
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TITLE

Testing a Fiber-Optic Heat-Flux Sensor for NASA's Venus-Landing Missions

OVERVIEW

To make NASA's future Venus-landing missions successful, sensors, electronics and other components need to be able to survive the surface of Venus. Venus's harsh atmospheric conditions include high temperature (~500 °C), high pressure (90 earth atm), and highly acidic gases. The objective of this research is to test a fiber-optic heat-flux sensor (HFS) that is able to operate at an ambient temperature as high as 500 °C with a 10-mW/m^2 heat flux sensitivity.

An HFS measures the temperature difference between the two sides of a transducer, with one of the sides in thermal contact with a heat source. Knowing the temperature difference and the thermal conductivity of the transducer, one can derive the heat flux coming out of the source using Fourier's thermal conduction law. There are many types of HFS, but all of the currently available HFS measure temperature with *thermocouples*, which cannot withstand high temperatures for long periods of time. To address this challenge, Dr. Duan's research group has been studying a new type of HFS based on optical fiber sensors, which are known for their high sensitivity and durability. In particular, a prototype HFS has been developed using a special high-temperature fiber Bragg grating (FBG). Such FBGs are able to withstand temperatures as high as 1000 °C. Previously, this HFS has been tested under the normal lab conditions. However, in order to demonstrate its survivability in the Venus atmosphere, a special interrogation and detection (I&D) system has to be used. **The research goal of this summer project is to build this I&D system and test its operation with the HFS.**

INTERROGATION AND DETECTION

To enhance the temperature tolerance of the I&D system, two unique methods are used. First, an LED is used as the light source. LEDs are more robust and better able to survive high temperatures compared to other light sources such as diode lasers. Second, only direct power measurement is involved in signal detection, and there is no delicate spectrometer in the I&D system.

Fig. 1(a) illustrates the principle of the proposed I&D scheme. Two FGBs are attached on each surface of the HFS and they are designed to reflect slightly different wavelengths. The reflected light, which contains two spectral peaks under the illumination of the LED, passes through an FBG filter, which acts as a wavelength discriminator as shown in Fig. 1(b). By properly designing the FBG filter, a differential detection scheme can be used to extract the information about the wavelength change of the FBGs under different temperatures. This leads to a background-free signal highly sensitive to the temperature difference between the top and the bottom surfaces of the HFS.

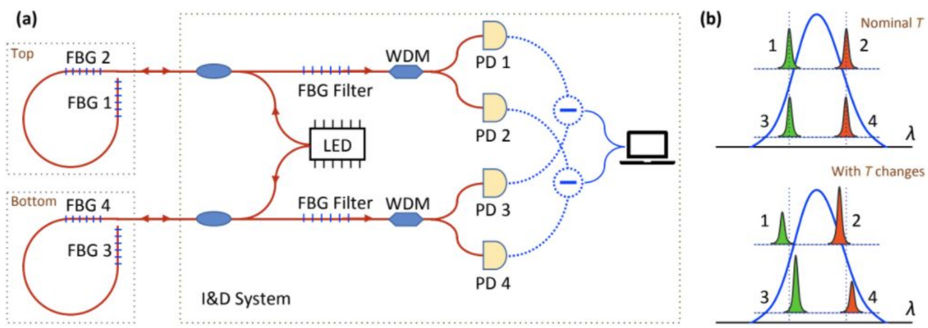

Fig. 1: (a) A conceptual layout of the I&D system. (b) Operating principle of the FBG filter-based detection scheme. PD: photodiode.

The main tasks of this summer project include:

1. Demonstrate a direct correlation between temperature change and the optical power transmitted through the FBG filter.
2. Experimentally verify the effectiveness of the differential detection scheme.
3. Calibrate the temperature and heat-flux sensitivity of the HFS.

All these tasks will be completed under the direct supervision of Dr. Duan.

POTENTIAL IMPACT

This research project will not only impact future Venus explorations, but could also benefit other NASA projects and missions. Fiber-optic sensors could help fulfill the prevalent need to measure temperature and heat flux under harsh conditions in space (e.g. the sun) and on earth (e.g. volcanoes and deep sea vents). The research and technology developed in this project could also pave the way for future research where fiber-optic sensors may be used to create other geophysical sensors (e.g. seismometer and gravimeter).

REMOTE PLAN

In case face-to-face projects are not possible due to COVID-19, the following remote plan will allow the student to execute the project remotely: Dr. Duan will take the actual measurements from the I&D system in the UAH lab and will send the data to the student to be processed remotely. The student will examine the sets of data to detect the relationship between temperature and optical power over several readings. Once a certain level of consistency is established, a calibration curve can be created and tested against. The same process will be performed for heat flux measurement. In addition, a computer code will be developed by the student to automatically predict temperature change and heat flux based on the sensor output and the calibration curve.

START AND END DATE

May 31st - August 6th