Temperature sensing system based on Fiber Bragg Grating (FBG)

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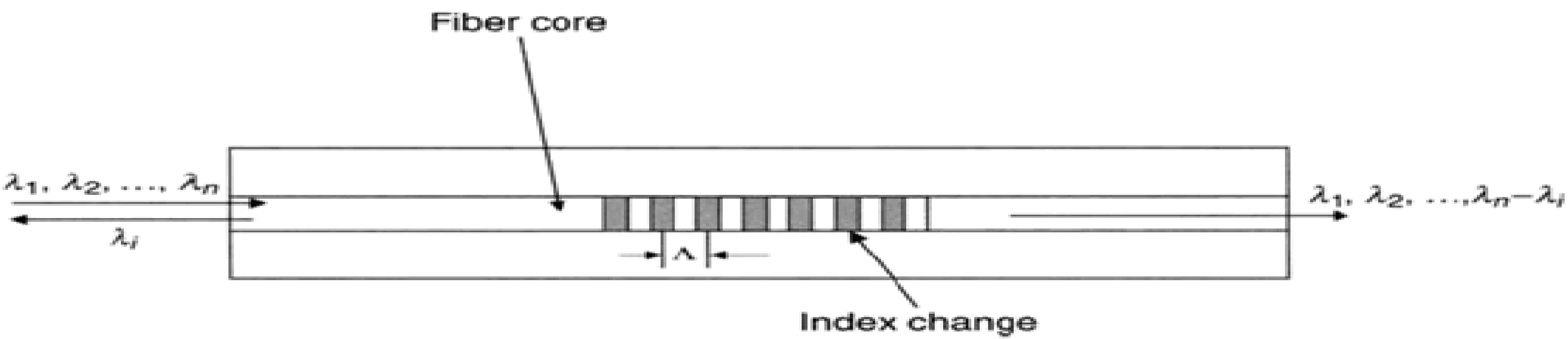
Fiber Bragg Grating

Fiber grating is made by periodically changing the refraction index in the glass core of the fiber. The refraction changes are made by exposing the fiber to UV-light with a fixed pattern



Schematic diagram of a fiber Bragg grating.

the **Bragg grating wavelength** can be expressed as

$$\lambda_B = 2n_{\text{eff}}\Lambda$$

Fiber Bragg Grating (FBG)provide some superior qualities making them very suited to special application.

1.FBGs match quite well with new composite material like glass or carbon fiber reinforced composite which are widely used in modern constructions ,like new airplanes or in wind power plants.

2.FBG can measure very high strain (>10000µm/m).

3.FBGs are small size and light weight.

4.FBGs are immune to electromagnetic interference .

5.FBGs are intrinsically passive (no electrical power necessary).

6.FBGs signals are not distance –dependent (up to >50 km connection length is possible).

7.On a single fiber many Fiber Bragg Gratings can be located in a row (>20 FBG) .

8.Long term stability is very high.

9.Good corrosion resistance.

10.Special version of FBGs are used at very high temperature (>700ºC.

11.FBGs are used in cryogenic environment because of low thermal conductivity of the single fiber feeding many sensors and their stable optical properties.

12.Very low magnetic field interaction.

13. Ease of installation (time ,cabling, testing)

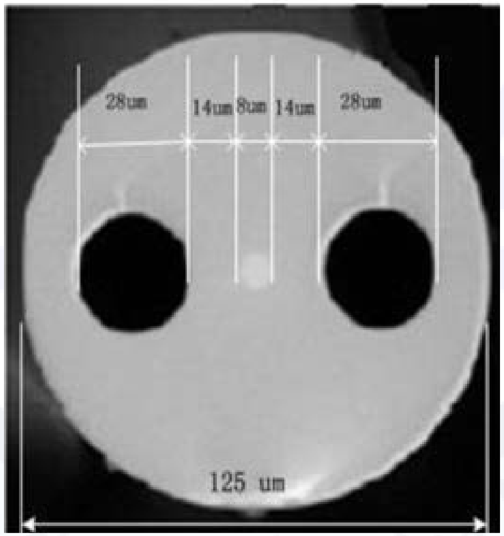
Sensitivity

The sensitivity of the sensor device is the output response capacity for a given input signal, basically quoted as the ratio between the output signal and its corresponding input signal value. Temperature sensitivity is the change in output of Bragg wavelength for a given input change in temperature

$$S = \Delta \lambda / \Delta T$$

Side hole fiber

Side-hole fiber (SHF) is a Hi-Bi fiber having two air holes running in the cladding and in parallel to the core. The SHF used in our work, with a scanning electron micrograph (SEM) of the cross section shown below, has core and cladding diameters of 8 um and 125 um, respectively. The two air holes with the same diameter of 28 um are located symmetrically in the cladding aside the core. The distance between the centers of the air hole and the core is 32 um. The difference in refractive index between the core and cladding is 0.0056.



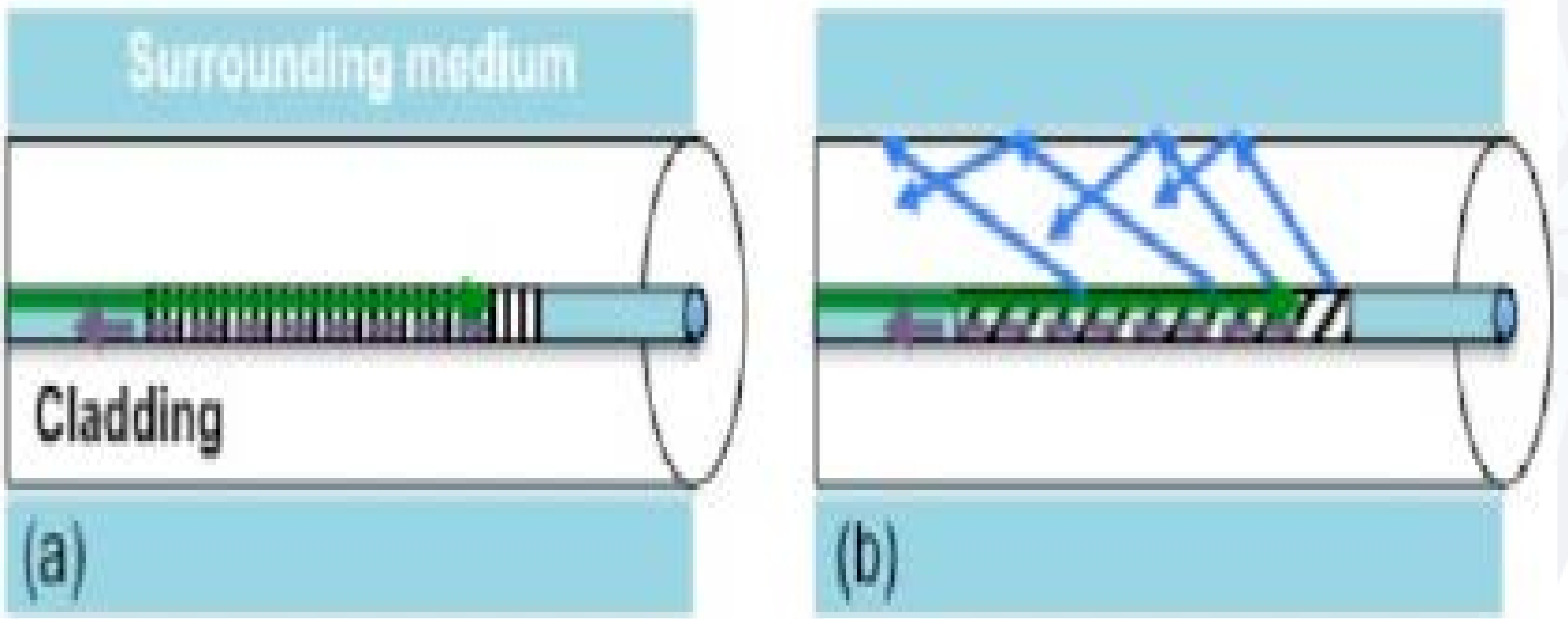
<u>Grating types</u>

The two types of FBG were used in our work

1. Normal fiber Bragg gratings

2. Tilted fiber Bragg gratings

In Normal FBGs, the grading or variation of the refractive index is along the length of the fiber (the optical axis), and is typically uniform across the width of the fiber. In a tilted FBG (TFBG), the variation of the refractive index is at an angle to the optical axis. The angle of tilt in a TFBG has an effect on the reflected wavelength, and bandwidth


Surrounding medium
Cladding
(a)
(b)

Coupled Mode Theory

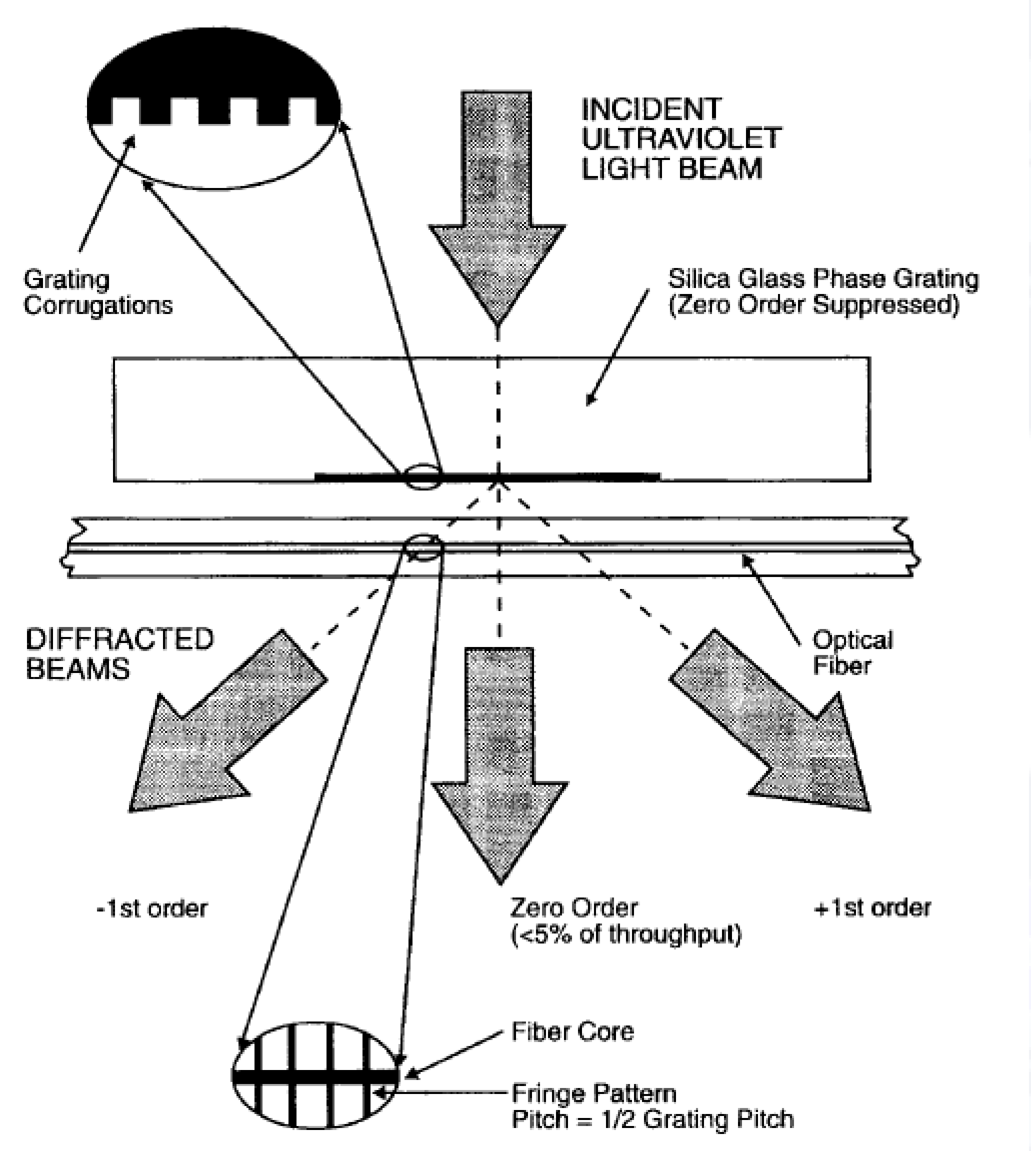
is used to see how mode coupling occurs by introducing forward- and backward-propagating modes. The equation of CMT represents fundamentally the wave propagation equation. The total transverse field may be described as a sum of both fields transverse guided mode and continuum of radiation modes.

Aim of the work

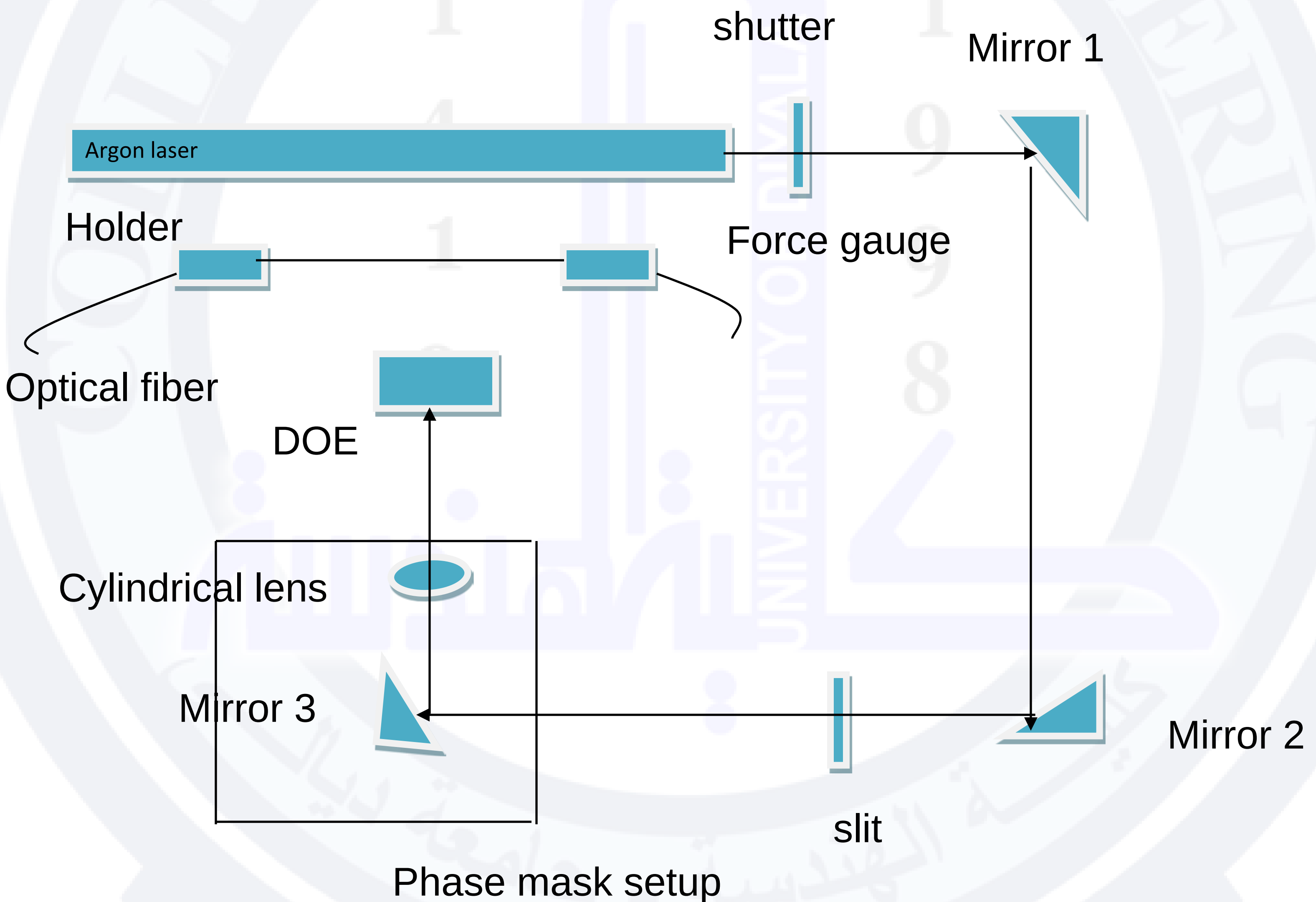
The objective of our work is to design ,build, realize and implement different Fiber Bragg Gratings (FBGs) configurations as temperature sensor element with a fully computerized interrogator sensor set up. The investigation is to involve normal Fiber Bragg Grating (FBG) integrated with Field Programmable Gate Array (FPGA) based Fiber Bragg Grating Analyzer (FBGA), normal Fiber Bragg Grating cascaded with a magnetic nanofluid with external magnetic field, tilted Fiber Bragg Grating written on a side hole fiber and finally tilted Fiber Bragg Grating written on the side hole fiber with alcohol filling the side holes.

Phase mask technique

Phase masks are surface relief gratings, typically etched in fused silica. A phase mask essentially serves as a precision diffraction grating that divides an incident monochromatic beam, often in the UV spectral range, into two outgoing beams. These two exit beams create an interference pattern in the region in which they overlap



Phase mask technique



shutter
Mirror 1
Argon laser
Holder
Force gauge
Optical fiber
DOE
Cylindrical lens
Mirror 3
Mirror 2
slit
Phase mask setup

Fiber Bragg Grating Analyzer (FBGA)

The structure of an FBGA consists of a spectral analyzer element, a detection unit and an electronic circuits. The wavelength components of the multiplexed signal containing a band of wavelengths is separated by the spectral element .The conversion from optical signal to electric signal is achieved by detection unit which is a single element or arrayed detector. The function of an FBGA is to provide fast measurements of the wavelength and power levels

photograph image for FBG interrogation analyzer

Fiber Bragg Grating Sensors

As well as being sensitive to strain, the Bragg wavelength λB is also sensitive to temperature. This means that fiber Bragg gratings can be used as sensing elements in optical fiber sensors.

In a FBG sensor, the measurement causes a shift in the Bragg wavelength, $\Delta\lambda_B$. The relative shift in the Bragg wavelength, $\Delta\lambda_B/\lambda_B$, due to an applied strain (ε) and a change in temperature (ΔT) is approximately given by,

$$\left[\frac{\Delta\lambda_B}{\lambda_B}\right] = C_S\epsilon + C_T\Delta T$$

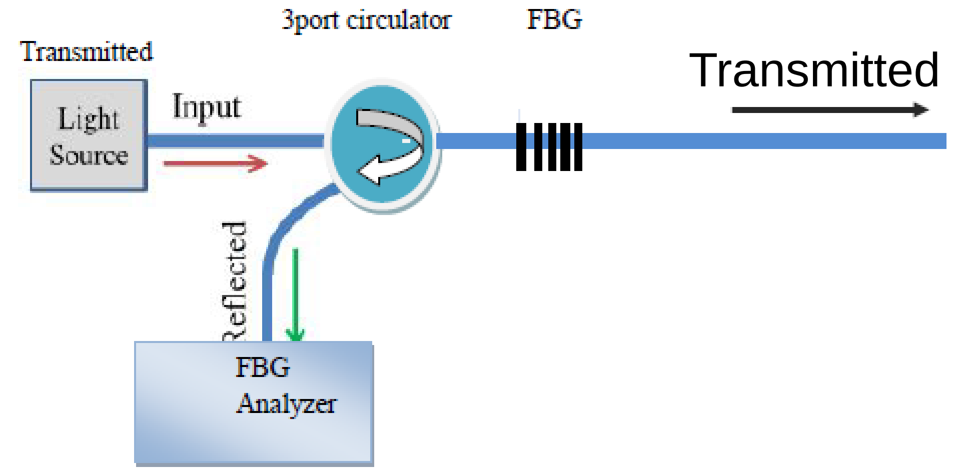
Fiber Bragg gratings can then be used as direct sensing elements for strain and temperature

The system setups

The experimental work was developed and implemented sequentially around on a motive to reach as high as possible temperature sensitivity of fiber Bragg grating intrinsic and extrinsic based fiber sensors. In each case an appropriate interrogator system was employed. The sequence evolved as:

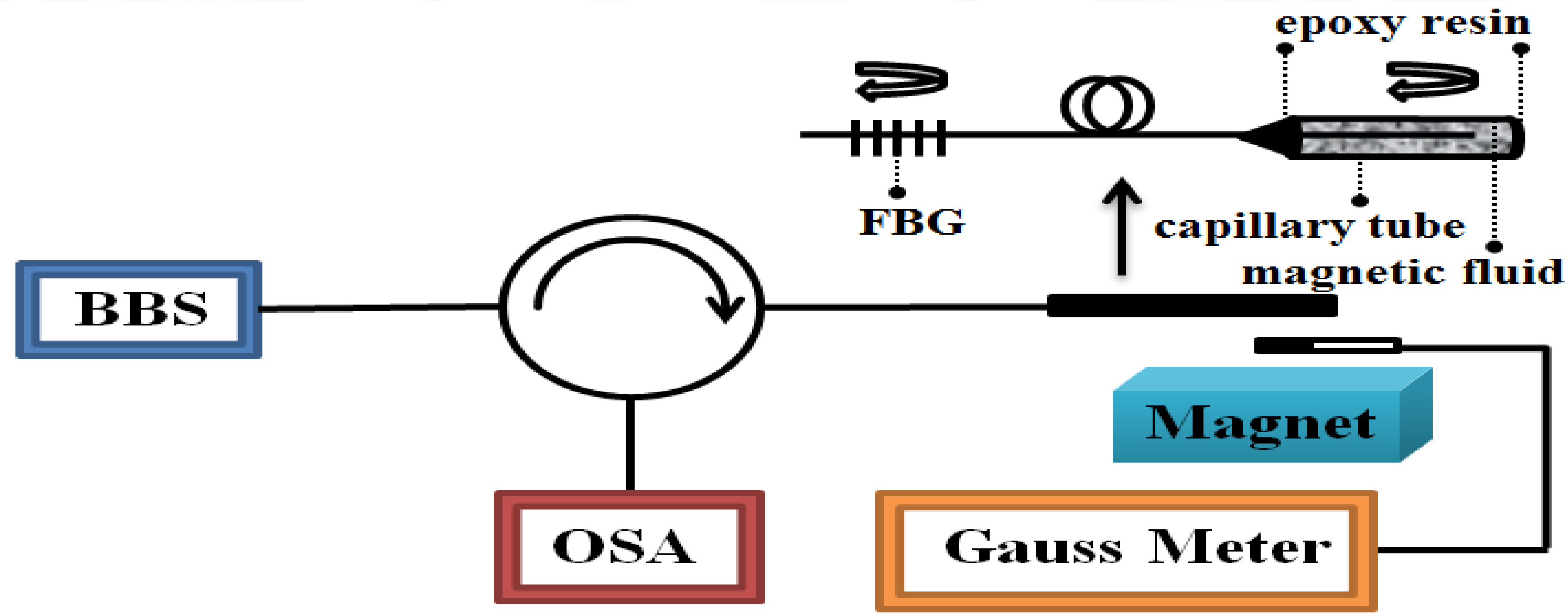
1. Ready made uniform fiber Bragg grating.
2. Home made fiber Bragg grating (using 244 nm Ar^+ laser) Combined with nano materials magnetic fluid (MF) in extrinsically cascaded fiber sensor geometry.
3. Home made tilted fiber Bragg grating (using 244 nm Ar^+ laser) written on side hole fiber.
4. Home made fiber Bragg grating (using 244 nm Ar^+ laser) written on side hole fiber with alcohol filled side hole geometry.

Setup 1



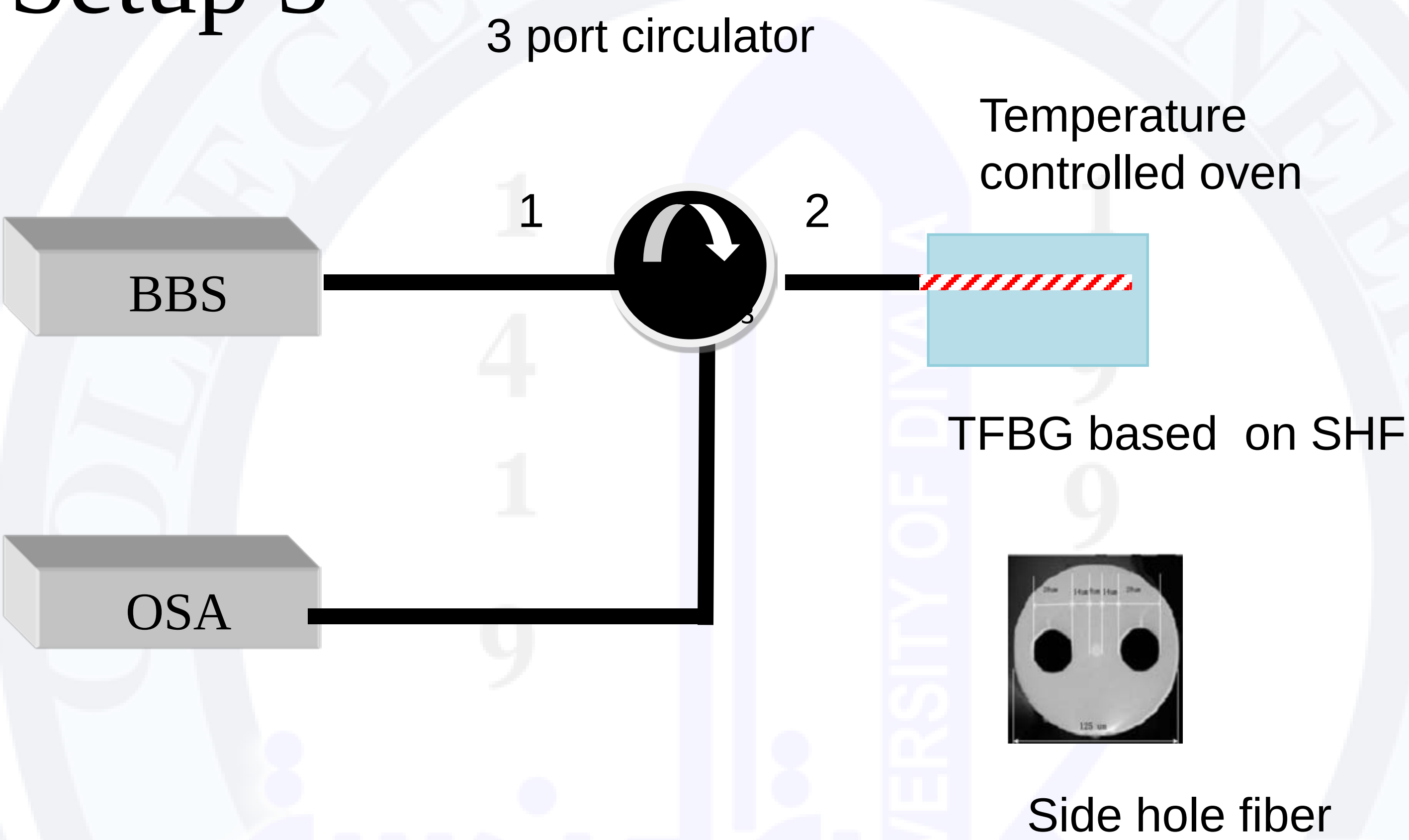
Ready made uniform fiber Bragg grating setup

Setup 2

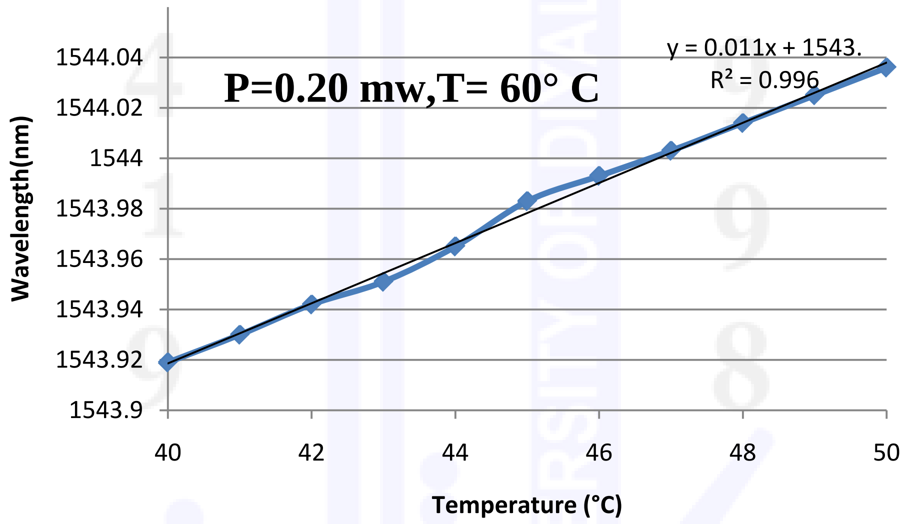


A Schematic diagram of a uniform fiber Bragg grating cascaded with a magnetic nanofluid in an integrated sensing system set up.

Setup 3

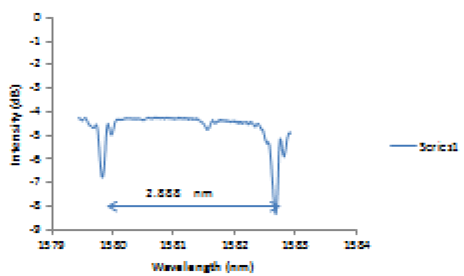


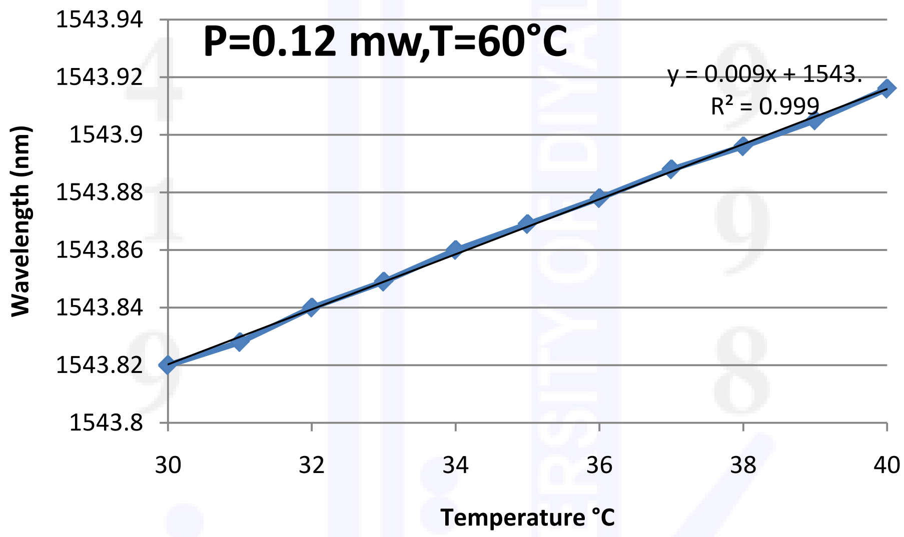
A schematic for the home made tilted fiber Bragg grating written on a side hole fiber



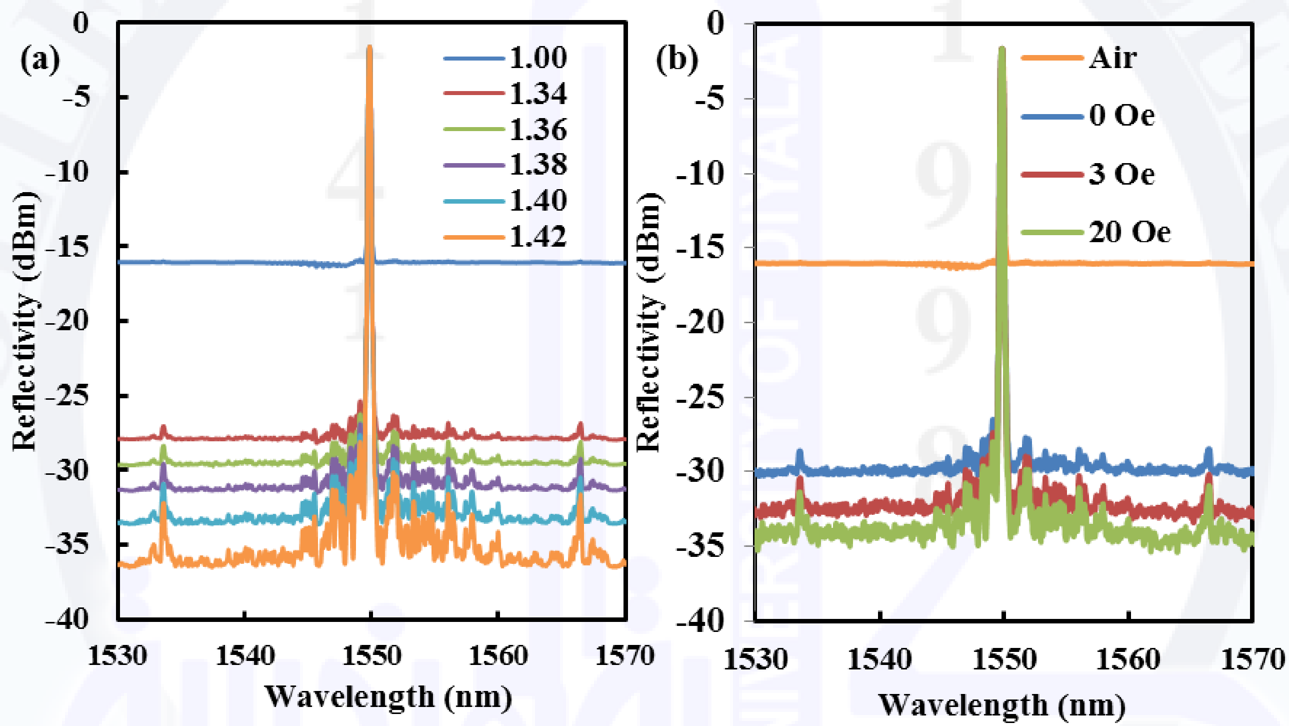
Relationship between the temperature and the Bragg wavelength (ascending)

Setup 3

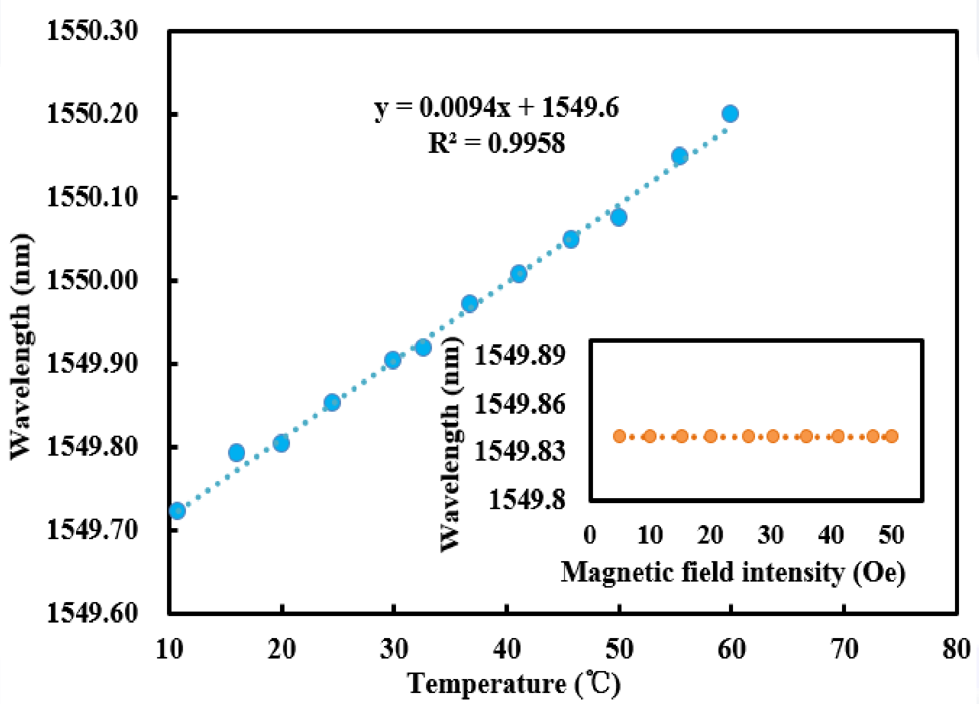




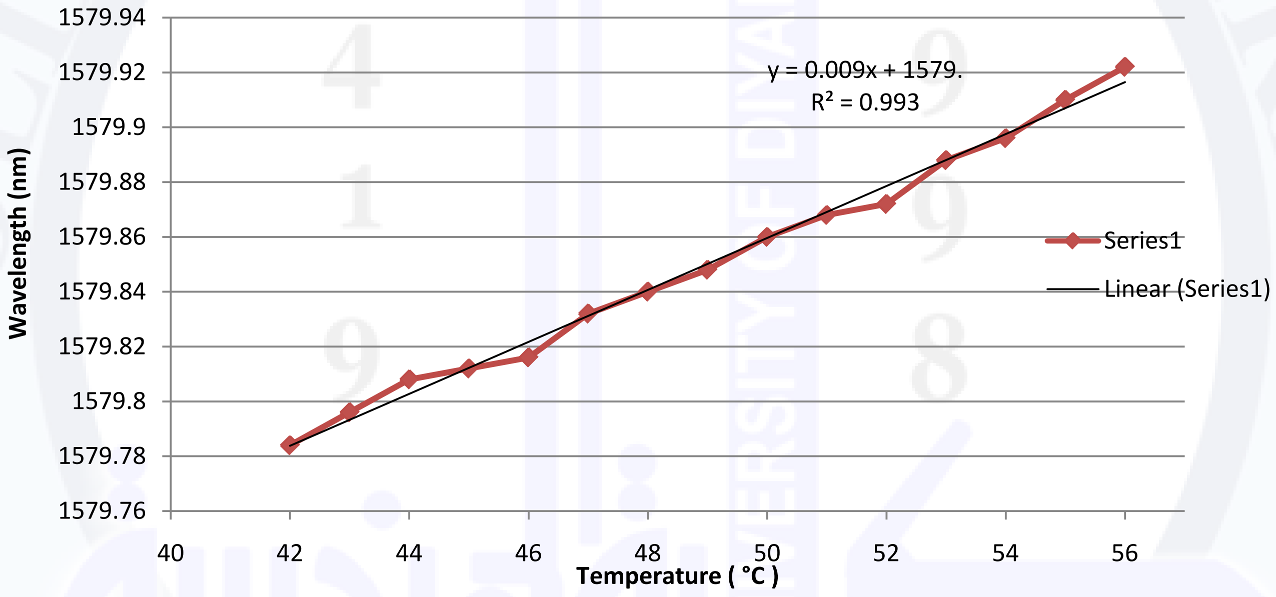
Relationship between the temperature and the Bragg wavelength (descending



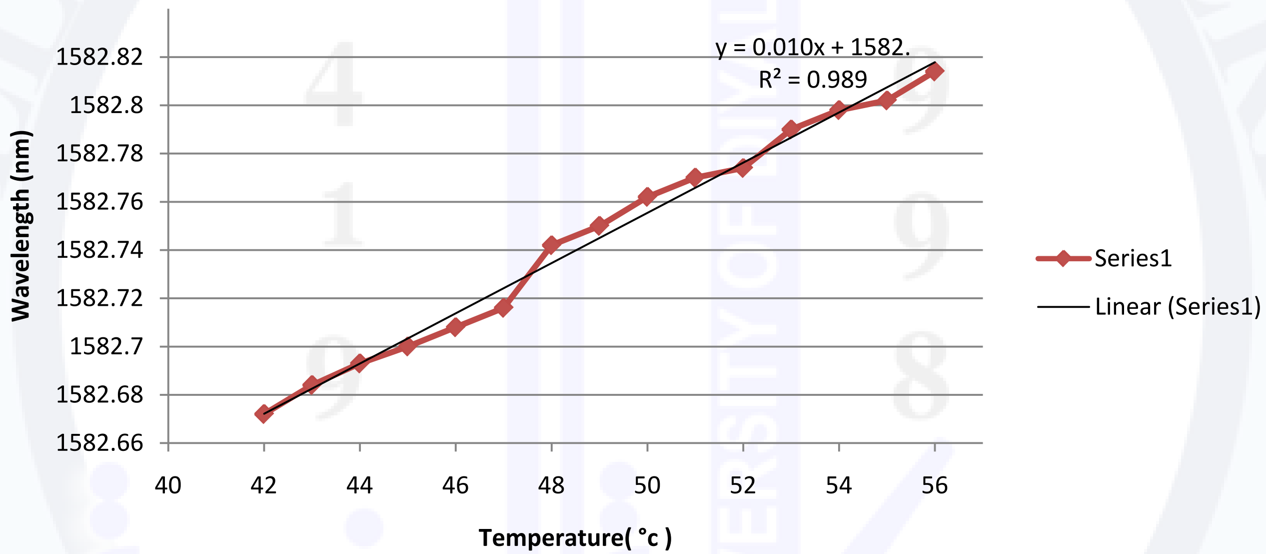
Reflection spectra of the FBG (a) under air and various index liquid. (b) Reflection spectra of the FBG under air and various magnetic field intensities



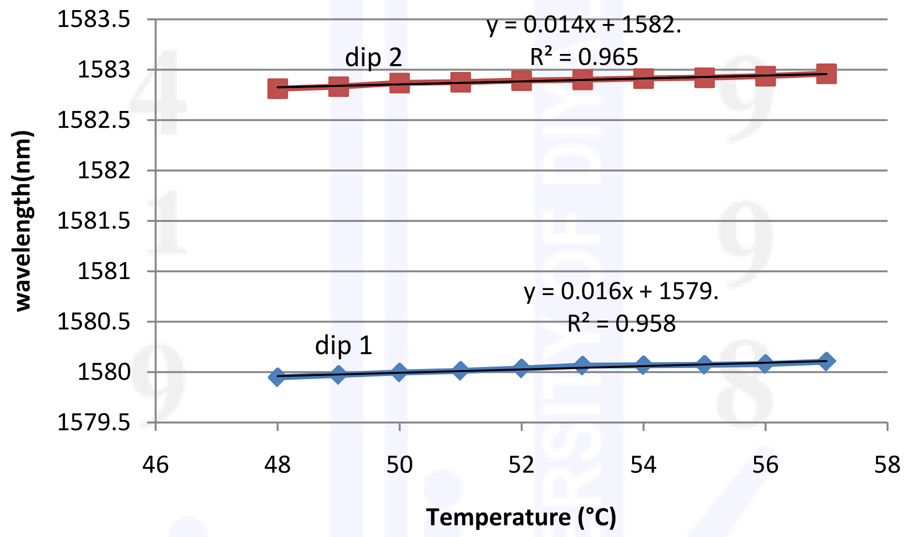
Relationship between the Bragg wavelength and the temperature.



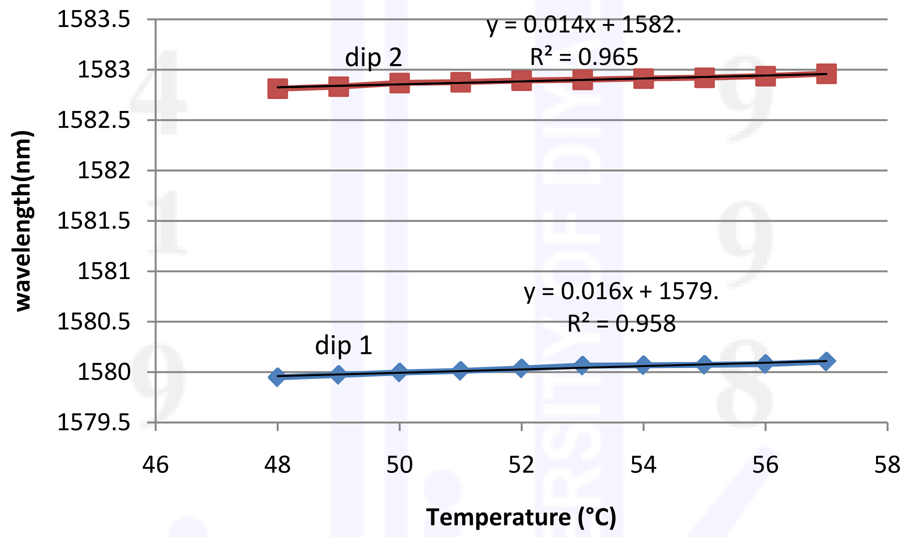
Relationship between temperature and Bragg wavelength (dip 1)



Relationship between the temperature and the Bragg wavelength (dip 2) .



Relationship between temperature and Bragg wavelength (dip1,dip2) for 7cm-long side hole fiber.



Relationship between temperature and Bragg wavelength (dip1,dip2) for 7cm-long side hole fiber.

Conclusion

The side hole fiber did not show improvement in the sensitivity Where gave as the same as first and second cases. It is clear that filling the tilted fiber Bragg grating side hole fiber with alcohol improved the sensitivity by factor of about 50% with linear behavior.

In conclusion despite the difficulty encountered in writing TFBG side hole fiber the result is promising for potential application that required higher precession measurements.

Future works

1. Investigate the response of the combination of the alcohol filled side hole fiber cascaded with magnetic fluid expecting higher sensitivity and better side mode suppression ratio (SMSR).

2. Design an engineer compact sensor unit incorporating Fiber Bragg Grating Analyzer (FBGA) instead of the Optical Spectrum Analyzer(OSA) in the optimum sensing element interface with microprocessor for actual field application.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Thank You