High Pressure and Temperature Sensing for the Oil Industry Using Fiber Bragg Gratings Written onto Side Hole Single Mode Fiber

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Abstract

We describe novel Bragg grating sensors based on single mode fiber made with side air holes. Measurements made at 12 kpsi and 100 C produced enhanced sensitivity and reduced thermal dependence compared to normal fiber Bragg gratings.

Introduction

Fiber Bragg gratings are of interest to the oil service industry as a potential candidate for multifunctional distributed sensors for well and reservoir monitoring. Environmental conditions in well bore applications typically reach 20 kpsi and 185 degree C., making fiber optics an interesting choice for a passive sensor. Fiber optic Bragg grating sensors have been used to measure longitudinal and transverse strain [1-3] as well as longitudinal strain and temperature [4-6]. High pressure measurements have also been made with Bragg gratings, but with poor pressure sensitivity [7]. Schlumberger's quartz based pressure gauges typically produce 0.01 psi resolution under high pressure and temperature conditions.

In both of the Bragg strain and pressure measurements, temperature greatly influences the Bragg reflection shift. By using dual overlaid fiber optic gratings at a single point it has been demonstrated that strain and temperature may be measured simultaneously by solving the two equations in the two unknowns [4]. Writing single or dual overlaid gratings onto single mode fiber with air holes in the cladding yields single and dual wavelength Bragg reflection at room pressure. Under high pressure conditions, dual and quadruple effective Bragg reflections are produced from stress induced birefringence in the core.

Experiments

In order to measure the pressure and temperature response of Bragg gratings in various fiber, single and dual overlaid gratings at 1300nm and 1550 nm were written onto Corning SMF -28 fiber, commercial polarization preserving fiber from 3M, Fibercore and Fujikura. Single mode fiber with two 35 micron diameter air holes in the cladding on opposing sides of the core were also written with single and dual overlaid gratings. Both the PM fiber and the side hole fiber were spliced onto normal SMF -28 fiber to seal the air holes and extend the fiber length from inside the pressure vessel and through a high pressure fiber feed through. The side hole fiber was sealed at both ends with SMF-28 to prevent fluid entering the side holes. The fibers were placed inside of a pressure vessel filled with silicone oil.

The demodulation electronics consisted of an optical spectrum analyzer and a dual wavelength scanning Fabry-Perot filter. Two LED broadband light sources at 1300nm and 1550 were connected to the FBG’s in order to allow simultaneous measurements of all Bragg reflection peaks. Pressure tests were made from 0-12 kpsi and 25 to 100 deg C separately and together.

Fig 1 shows the typical response of a FBG written onto SMF-28 fiber and exposed to high pressure and temperature. The response at 1300nm is nominally 0.03 pm/psi and 8 pm/deg C. As expected, the family of curves shows the importance of separating temperature from the pressure measurement.

Fig 2 shows response of side hole fiber written with a FBG to pressure at 13 and 7891psi at 1300nm as measured with an OSA. The splitting of the single peak into two distinct Bragg reflections is caused by stressed induced polarization in the core yielding two Bragg reflections from the two polarization axes

Fig 3 shows a plot of wavelength shift vs pressure for SMF-28, PM fiber and Side hole fiber. Note that the peak to peak wavelength separation of the side hole optical fiber provides the greatest pressure sensitivity. The sensitivity of the PM fiber has the next to highest sensitivity and the normal SMF-28 based FBG has the lowest.

Fig 4 shows a plot of peak to peak separation of side hole fiber vs. pressure and temperature from 25 to 100 deg C. One key result is that by measuring the peak to peak spectral separation of the side hole FBG to determine pressure, the compensation required due to temperature changes is drastically simplified. This is due to the side hole fiber grating peak to peak spectral separation being nearly independent of temperature.

By combining the higher peak to peak sensitivity of the side hole fiber grating pressure sensor with its reduction of sensitivity to thermal changes, it is possible to effect a distributed side hole fiber grating pressure sensor system that allows for distributed pressure and temperature measurements in a oilfield downhole environment.

Conclusions

A side hole fiber Bragg grating based pressure sensing system has been described which offers superior pressure sensitivity to fiber gratings written onto conventional single mode or polarization preserving optical fiber. In addition, the temperature sensitivity of the side hole fiber grating sensor is much lower allowing straightforward temperature compensation techniques to be used to form a practical downhole distributed pressure measurement system.

References

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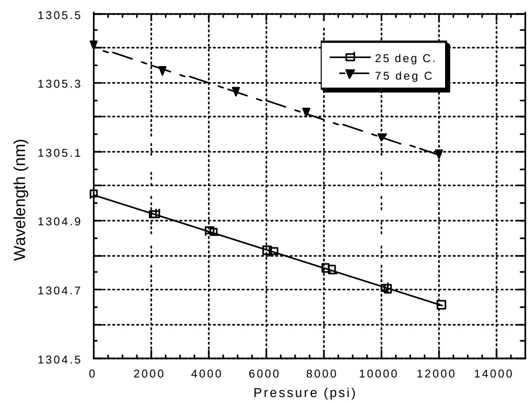

Fig. 1 Response of normal FBG with pressure and temperature.

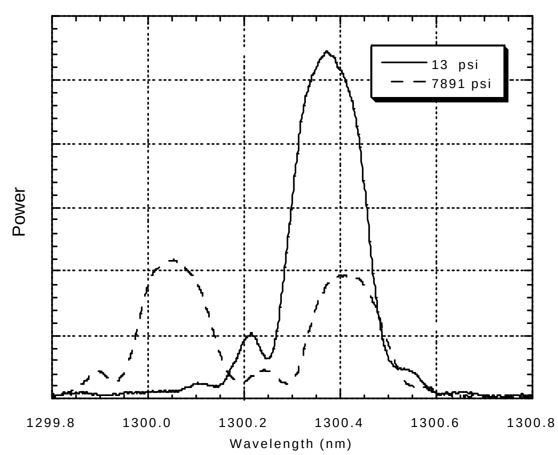

Fig. 2 Splitting of Side Hole FBG under pressure.

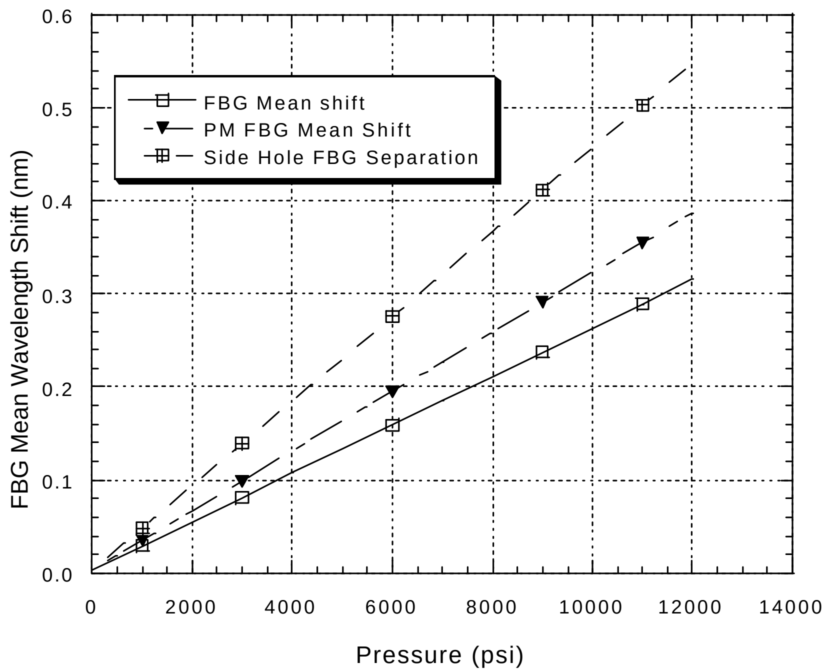

Fig. 3 Mean wavelength shift of FBG's in three types of fiber.

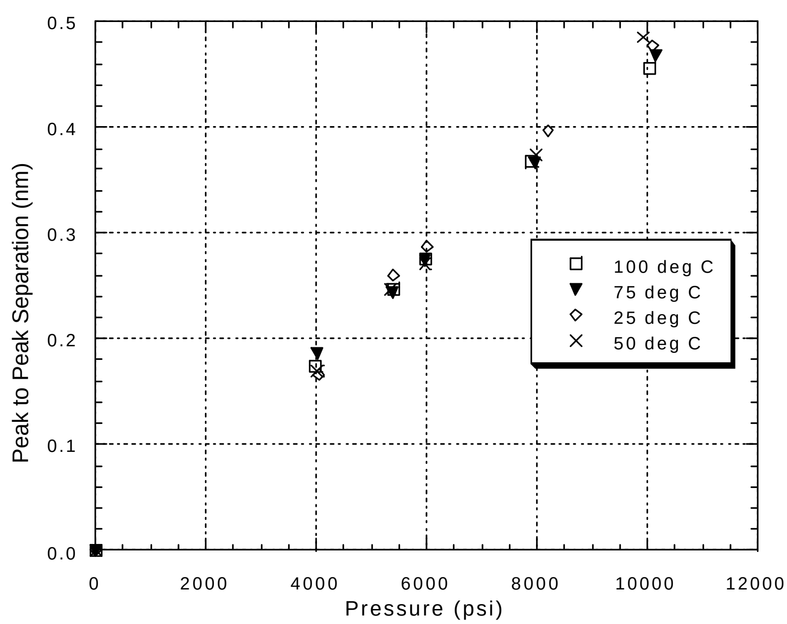

Fig. 4 Response of Side Hole FBG with pressure and temperature.