Contact microphone using optical fibre Bragg grating technology

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Abstract. A contact microphone using optical fibre Bragg grating has been developed. It enables one to listen and record a human voice and/or breathing by monitoring the vibration generated by the outer wall of the throat during speech. This system can have many applications such as detecting defects in vocal folds, measuring and monitoring the vibration and deflection generated by intubations of a patient throat and other voice related problem, low level speaking recording and transmitting is also possible, the microphone can be also used to monitor breathing and the system can be used as a microphone in very harsh environments for example it would allow one to hear the patient during a cat scan.

1. Fibre Bragg grating background
An increasingly used method of sensing temperature, strain etc. is the use of fibre Bragg gratings. Fibre Bragg techniques have been demonstrated by several research groups [1]. One of the benefits of using intrinsic optical fibre sensors such Bragg gratings or fluorescent emission is that the sensing element is intrinsic to the fibre. This is particularly important for the measurement of temperatures within a manufacturing environment, where the equipment will be subject to a relatively dirty environment.

The most common way for manufacturing a fibre Bragg grating is by laterally exposing the core of a single-mode fibre to an ultraviolet (UV) radiation through a phase mask or an interferometer [2]. The UV exposure creates a fixed refractive index modulation of the core of the fibre producing a fibre Bragg grating [2]. Figure 1 illustrates the principle of the Bragg grating. The figure shows a spectrum of light entering the grating, the spectrum of the light transmitted through the grating and the spectrum of the light reflected by the grating.

![Figure 1. Bragg grating properties](image-url)
The Bragg wavelength is defined by Bragg’s law, which states that:

\[ \lambda_B = 2 \times n_{\text{eff}} \times \Lambda \]

where \( n_{\text{eff}} \) is the effective refractive index of the core and \( \Lambda \) is the Bragg grating period [2].

The Bragg wavelength of a given fibre grating depends on the period of the grating and the refractive index of the material (Bragg’s Law). Both of these parameters are sensitive to mechanical strain and the temperature field within the grating [3] and any change in strain or temperature will modify the spacing between the gratings of a Bragg sensor and the refractive index of the core of the fibre. It is therefore necessary to develop alternative methods of detecting a wavelength or a wavelength shift without using an expensive spectrum analyser or wavelength meter. The basic idea behind doing that detection is to relate the wavelength change caused by a measurand on the Bragg grating to an intensity change that is easily measurable using photodetectors. This led to the design and development of the following system:

2. Thin film dense Wavelength Division Demultiplexer (DWDM) technique

A broadband spectrum (C-Band) is launched in the optical system by an ASE light source. The light source power output is stabilised and its value is 13.7dBm. It is important to have a stabilised power since the wavelength changes therefore the temperature measured is related to an intensity change. The spectrum is then going through a circulator that makes the signal circulate without splitting it and also acts as an isolator preventing damage on the light source due to back reflection. The broadband spectrum then reaches a fibre Bragg grating that is used for the sensing. The Bragg grating will reflect just a narrow peak at the Bragg wavelength. That peak is reflected back toward the circulator that directs it to the thin film dense WDM. DWDMs are commonly used in telecommunication systems to multiplex (combine) or demultiplex (separate) an optical signal; this allows signals of different wavelengths to travel in one single fibre. In this particular case, the thin film dense WDM is used in this case to relate wavelength and intensity as explained above. Using a photodetector on each channel of the thin film dense DWDM would allow a temperature range of approximately 1200°C to be achieved. However this assumes that the sensing fibre could sustain such a temperature without permanent damage. A similar set-up was used to monitor temperature during milling [4].

Using the spectral specifications given by the manufacturer of the thin film dense WDM, it is possible to relate the optical power (transformed into voltage by the photodetectors) to the reflected wavelength and therefore the temperature. The layout is illustrated in figure 2.
As the vibration is generated, the wavelength of the sensing grating increases and decreases. Since the spectrum of the thin film dense DWDM channel is steady, it results in a decrease in the intensity output on that channel (area between the two spectrums). Figure 3 illustrates the principle.

The DAQ card allows for the measurement of deflections and vibration, the audio card has its DC offset compensated allowing for straight vibration measurement without the need to calibrate for other deformations and temperature changes.
3. **Sensor arrangement for measuring throat vibrations**

The following arrangement allows for measurements of different factors using a fibre Bragg grating. The arrangement improves the performances of a Bragg grating for monitoring vibrations. It also protects the optical fibre from breakage or permanent damage by avoiding overstretching. Also the membrane allows for bigger surface measurements instead of point sensing since, all the surface of the membrane does the sensing instead of only point sensing if the Bragg grating was used on it own (one small Bragg grating can be used to measure a big object or long distances).

The main body consist of half a cylinder with clips on each side, allowing holding the membrane into place without having to pierce it. These clips are then bolted onto the main body and the strap. The little holes on the side are used to feed the optical fibre in and allow the fibre to come out the other side. The system is shown in fig. 4.

**Figure 4.** Fibre Bragg grating based throat vibration interrogation device.
Figure 5. Positioning.

Figure 5 shows the positioning of the device to measure throat vibrations during speech (and/or breathing) or as a contact microphone for very noisy or electromagnetic or other extreme environment.

Figure 6. Fibre Bragg grating sensor arrangement.

Figure 6 schematically represents the sensor arrangement. As the throat vibrates it pushes the membrane forward elongating the grating and therefore creating a change in the Bragg wavelength. The membrane also protects the fibre from overstretcing and breaking.
Figure 7. Example of the vibration generated on the throat outer surface by saying “hello”.

Figure 7 shows an example of the vibration generated on the throat outer surface by saying “hello”. The figure on the left is a Fast Fourier Transform of the signal to generate a frequency read out. Figure on the left is a plot of amplitude vs. number of samples of the signal.

4. Conclusions
The system and sensor arrangement was proven to be suitable for contact microphone applications. The voice and breathing heard are clear and easily monitored in audio real time. The frequency range of the device is 0 to 2MHz covering widely the audible voice range and possibly allowing for other future applications such as pipe monitoring etc.

References
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