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SMS Fibre Structure for Temperature Measurement Using a Simple Intensity-Based Interrogation System

Agus Hatta
Dublin Institute of Technology, ahatta@dit.ie

Ginu Rajan
Dublin Institute of Technology, ginu.rajan@dit.ie

Yuliya Semenova
Dublin Institute of Technology, yuliya.semenova@dit.ie

Gerald Farrell
Dublin Institute of Technology, gerald.farrell@dit.ie

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SMS fibre structure for temperature measurement using a simple intensity-based interrogation system

A.M. Hatta, G. Rajan, Y. Semenova and G. Farrell

A singlemode–multimode–singlemode (SMS) fibre structure for temperature measurement that utilises a simple intensity-based interrogation system is proposed. The temperature dependence of the SMS fibre structure utilised as a sensor is investigated numerically and experimentally. It is found that a strong temperature dependence for the SMS fibre structure exists at selected wavelengths. The temperature characteristic at such wavelengths is linear in nature and can be used for temperature measurements. The proposed temperature sensor offers a high resolution and accuracy, and also benefits from a simple configuration and low cost when compared to other fibre-optic temperature sensors.

Introduction: Singlemode–multimode–singlemode (SMS) fibre structures have been demonstrated for use as bandpass filters, edge filters, and wavelength encoded temperature sensors [1–3]. Multimode interference (MMI) is the basic operating mechanism of such SMS fibre devices, where interference between modes in the multimode fibre (MMF) occurs along the MMF length. The SMS structure can generate minimum or maximum interference at specific MMF lengths. By precisely optimising the MMF length, different device functions can be implemented.

SMS structures demonstrate temperature dependence and previous investigations have shown that the effect of temperature on the wavelength response of an SMS fibre device can be compensated for by using a suitable packaging material [4]. It is also possible to exploit this temperature dependence to implement a temperature sensor. However, to date the temperature information is extracted by measuring the temperature-induced shift in the peak wavelength of the SMS spectrum [3], which will involve a complex and expensive interrogation system. Other established methods to measure temperature using fibre-optic sensors include a singlemode–multimode (SM) fibre structure [5], FBG sensors, interferometric sensors, etc. However, these techniques also require complex interrogation units to extract the temperature information. Therefore, a simple and reliable fibre temperature sensor is needed, which can be interrogated using a simple intensity-based system. Our recent studies demonstrated that SMS structures can be used for intensity-based wavelength measurements in a ratiometric scheme with very low temperature dependency. However, by properly utilising the temperature properties of an SMS fibre structure used as an edge filter it is possible to implement a temperature sensor that utilises a simple intensity-based interrogation technique. In this Letter, we propose such a temperature sensor based on an SMS fibre structure, which has high temperature dependence at selected wavelengths. Theoretical simulation of the temperature dependence of the SMS structure is presented together with experimental validation.

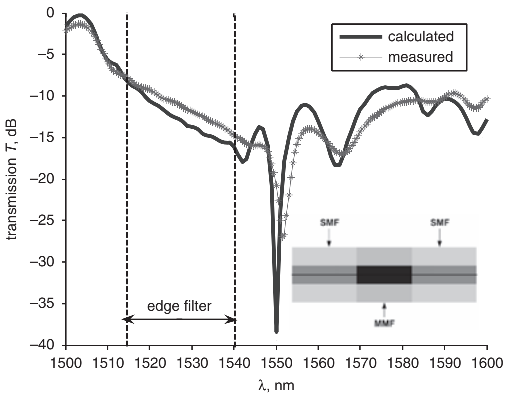

Fig. 1 *Calculated and measured SMS fibre structure spectral response*

Inset: Schematic structure of SMS fibre structure

SMS fibre structure: A schematic of an SMS fibre structure is shown in the inset in Fig. 1. The SMS fibre structure is fabricated by splicing a specified length of MMF between two singlemode fibres (SMF). To design an SMS fibre structure device, a modal propagation analysis (MPA) for linearly polarised (LP) modes is used [1, 6]. It is shown that, at a re-imaging distance, the SMS fibre structure is highly wavelength dependent and operates as a bandpass filter [1, 6]. The peak wavelength of the bandpass filter response can be tuned by varying the MMF length [6]. For example, based on the fibre parameters in [2, 6], an SMS structure with a length of MMF $L = 44.12$ mm has a bandpass response with a peak wavelength at 1502 nm, as shown in Fig. 1. To investigate the application of this SMS structure as a temperature sensor, the structure was fabricated and the impact of temperature on the spectral response was studied to determine which portion of the response is most sensitive to temperature.

The SMS fibre structure was fabricated by using a Fujikura CT-07 cleaver and a Sumitomo type-36 fusion splicer. The spectral response of the SMS fibre structure was measured using a tunable laser and an optical power meter. The measured result is shown in Fig. 1, and shows good agreement with the calculated results. The discrepancy between the calculated and measured results is most likely a consequence of splice insertion losses and also could result from small fibre core offsets [7].

Temperature dependence: It is well known that the effect of temperature on the fibre can be expressed using two parameters: the thermal expansion coefficient (TEC) and the thermo-optic coefficient (TOC). The TEC characterises the physical expansion or contraction of the material's volume, while the TOC characterises refractive index change in response to temperature change. Using the TEC and TOC it is possible to determine the change in the core diameter of fibres, MMF length, and refractive indices owing to a temperature variation.

To calculate the temperature dependence (TD) of the transmission (T) response, we assumed TEC $= 5 \times 10^{-7}/^{\circ}$C and TOC $= 6.9 \times 10^{-6}/^{\circ}$C for both the SMF and the MMF [3, 5]. For example, within a temperature range 50–200°C, a TD can be defined as TD $= T(200^{\circ}\text{C}) - T(50^{\circ}\text{C})$ in dB. Fig. 2 shows the TD of the designed SMS fibre structure. It can be seen from the Figure that within the edge filter wavelength range TD is low. For example, at the wavelength of 1530 nm the TD is 0.62 dB over a 150°C temperature range. However, significantly higher TDs can be obtained outside the edge filter wavelength range. For example, at the wavelength $A = 1509.5$ nm and $B = 1554$ nm, the TD is 1.79 and −7.43 dB, respectively.

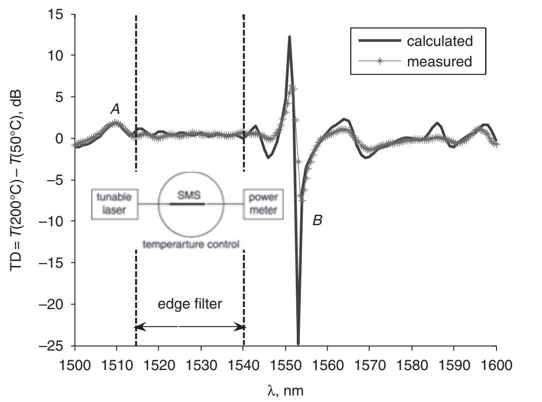

Fig. 2 *Temperature dependence of SMS fibre structure*

Inset: Schematic of measurement setup

For experimental verification the SMS fibre structure was attached to an integrated temperature controller IKA RCT. A tunable laser and optical power meter were used to measure the TD. A schematic of the measurement setup is shown in the inset in Fig. 2. The measured TD shows a good agreement with the calculated result and is shown in Fig. 2.

The temperature dependence of the transmission at the wavelengths A and B are presented in Fig. 3. The transmission values were measured in the temperature range 50–200°C with an increment of 10°C. The measured and calculated results show good agreement. Discrepancies are most likely a result of fusion splice loss, core offset errors and marginal differences between the designed length of the MMF section (used in the calculations) and the actual fabricated length. The slopes of the temperature dependencies were measured approximately as 0.0122 and -0.0508 dB/°C for the wavelengths $A = 1509.5$ and $B = 1554$ nm, respectively, providing potential temperature sensor resolutions of ~1 and ~0.2°C (assuming the accuracy of a typical commercial optical power meter is 0.01 dB). This confirms that the high TD of an SMS fibre structure at selected wavelengths can be utilised as an intensity-based temperature sensor.

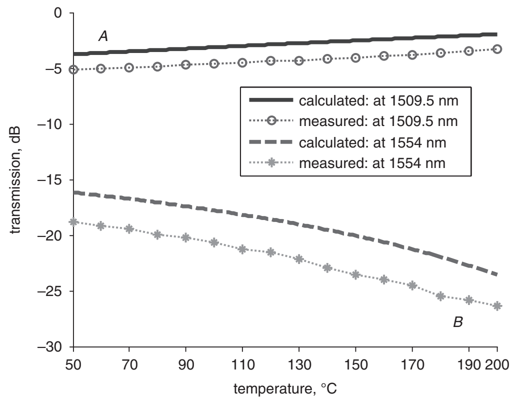

Fig. 3 *Transmission of SMS structure against temperature at wavelengths of 1509.5 and 1554 nm*

To avoid the effect of source signal power variation, an all-fibre ratiometric power measurement technique can be used. A ratiometric system consists of an optical source, a fibre splitter the two arms of which are connected to the SMS fibre structure (temperature sensor arm) and a reference arm. The output powers of the two arms are monitored by two optical power meters. The temperature can be determined by measuring the ratio of two output powers, assuming a suitable calibration has taken place.

Conclusions: The temperature dependence of an SMS fibre structure is investigated and proposed as an intensity-based temperature sensor at selected wavelengths. The sensor has a temperature range 50–200°C and a high temperature resolution of about 0.2°C. The proposed sensor can utilise a simple interrogation technique and can provide high-speed measurement for a range of temperature sensor applications.

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A.M. Hatta, G. Rajan, Y. Semenova and G. Farrell (*Photonics Research Centre, School of Electronic and Communications Engineering, Dublin Institute of Technology, Dublin 8, Dublin, Ireland*)

E-mail: ahatta@dit.ie

A.M. Hatta: On leave from Engineering Physics Department, Institut Teknologi Sepuluh Nopember (ITS), Surabaya, Indonesia

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