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Enhanced Relative Humidity Sensor via Diameter of No-Core Fiber Structure

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Abstract: Single mode-no core-single mode fiber structure with a section of tuned no-core fiber diameter to sense changes in relative humidity has been experimentally demonstrated. The sensor performance with tuned NCF diameter was investigated to maximize the evanescent fields. Different tuned diameters of of (100, 80, and 60)µm were obtained by chemical etching process based on hydrofluoric acid immersion. The highest wavelength sensitivity was obtained 184.57 pm/RH% in the RH range of 30% – 100% when the no-core fiber diameter diameter was 60 µm and the sensor response was in real-time measurements.

Keywords: Fiber optics sensors, Fiber optics, humidity sensor.

Introduction

Nowadays, optical fiber sensors based on multimode interference with different structures such as single mode–multimode–single mode (SMS) fiber have been intensively researched and investigated. This is particularly interesting due to their unique advantages of small size, immunity to electromagnetic radiation and high sensitivity, as well as cost effectiveness [1, 2]. However, the traditional multimode fiber (MMF) which is often used as a sensing head puts some limitations on the sensor sensitivity. Therefore, one of the approaches applied to extend the sensitivity range of such sensors was chemical etching to corrode the MMF cladding and even the core [1]. Recently, no-core fiber diameter has been widely used as a substitute for an etched MMF due to its high to the external environment which results from the lack of cladding. Therefore, optical sensors based on the single mode-no-core-single mode fiber (SNCS) structures have become potentially useful for a Wide range of applications specifically in refractive index (RI), humidity and temperature measurements [1-6].

Relative Humidity (RH) has significant impact in the measurements and monitoring of numerous fields of daily life such as weather monitoring, food industrial production, medical diagnoses and electronic devices [1, 2, and 5]. Electronic RH sensors are based on controlling the changes in electrical conductivity or capacitance have the disadvantage of inaccuracy due to electrical leakage in a high humidity environment. Compared with electronic RH sensors, fiber based sensors offer stable sensing, remote monitoring and fast response .Up to date, different kinds of optical fiber humidity sensors (OFHS) with different fiber types have been reported such as fiber Bragg grating (FBG) [7], long period grating (LPG) [8], and photonic crystal fiber (PCF) [9] .This approach has motivated researches to find solutions to improve the sensitivity of these OFHS, such as adopting new structures or modifying fiber structure [1,4]. However, the suggested solutions add more complicity to sensor fabrication and increase the cost. OFHS based on SNCS structures seem promising in terms of low-cost, ease of fabrication and high sensitivity. As RI is a function of RH, so the increase of RI of the surrounding air will lead to increase the sensitivity of SNCS sensor where the surrounding air works as a cladding of NCF [5]. In addition, decreasing the diameter of the NCF was applied for RI sensors and showed a significant increase in the sensitivity [5]. In this paper, we proposed and demonstrated an RH sensor based on hetero-core structured fiber, which comprises of 58 mm length of NCF sandwiched between two single-mode fibers (SMF). The sensing region of this sensor is confined in the NCF segment with basically of 125µm diameter. The influence of NCF diameter on the RH sensor sensitivity was investigated. The NCF diameter was etched chemically to increase the interaction between the evanescent field and the humidity of the external environment.

Experimental Part

Sensing Structure fabrication

The schematic of the SNCS hetero-core structure is shown in Figure. 1. A section of 58 mm length of NCF (FG125LA from Thorlabs) was spliced between two standard single-mode fibers SMFs (corning SMF-28). The NCF has core/cladding diameters of 9/125 µm. The fibers were spliced with the automatic mode of the fusion splicer (Fujikura FSM-60S). The surrounding medium of the NCF with lower refractive index considered to be the cladding layer to achieve the internal total reflection of light wave propagation. Light wave transmission between two different core diameters of single mode fiber and No core fiber excited higher order modes. Those modes would interfere in no-core section and retransmitted to single mode fiber due to multi-mode interference (MMI) effect.

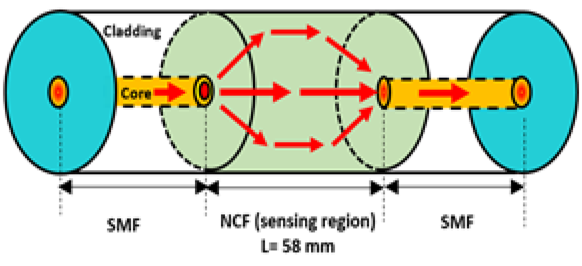


Fig.1 Schematic of the SNCS hetero-core structure.

The lack of NCF's clad may contributes to the enhancement in the fraction of the evanescent wave power. The variation of RH of the surrounding environment will be reflected as a change in the effective refractive index of the NCF. To enhance the SNCS sensor sensitivity to the changes of the RH, the fraction of light interaction with the external environment has to be enlarged. This can be achieved by reducing the NCF diameter by different means like annealing [10] and chemical etching .In the present work chemical etching method has been performed. This decrease in the diameter will increase the interaction of RH with evanescent waves. The etching process was carried out by immersing the NCF in hydrofluoric (HF) (~40%) acid solution. Etching time controls the etching diameter of the etched fiber. When the diameter of the NCF reduced to the wanted value, the fiber was rinsed with water. The etched diameter of NCF was reduced from125 µm to 100µm, 80 µm then to 60 µm. The calculated average-etching rate of the NCF diameter removal was about 0.83 µm/ min.

Experimental setup

Figure 2 shows the schematic of the experimental setup for humidity sensing system based on SNCS fiber structure. The spectrum (1500 -1600 nm) from a broad band light source (BBS) (model: SLD1550S-A1 from Thorlabs) was launched into one end of SNCS fiber structure and the transmitted spectrum was detected on other side by an optical spectrum analyzer (OSA) (OSA (YOKOKAWA, Ando AQ6370) with 0.02nm resolution.

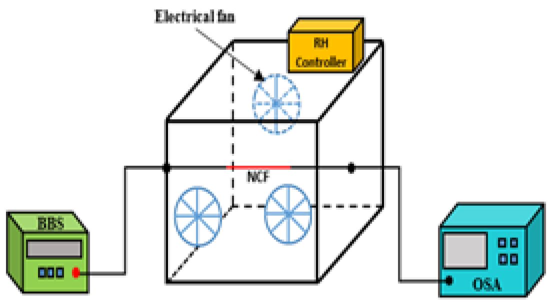


Fig.2 schematics diagram of RH% sensor based on SNCS fiber hetero-core structure.

The fabricated SNCS fiber structure of the sensor was placed into sealed chamber with three fans. One of the fans is to provide the humidity to the chamber while the others are used to accelerate the humidity spread in the chamber access. Electronic RH meter was connected to the chamber to control the RH changes from 30 to 100% RH under a constant temperature of 25 °C. In this experiment, the SNCS fiber structure was fixed in the chamber sides to avoid the induced losses by fibers bending.

Results and discussion

Firstly, the response of the basic SNCS fiber structure without etching (with 125 µm diameter of NCF) towards the ambient RH was investigated. After placing the structure of the sensor within the chamber, the RH was varied slowly from 30% to 100%, while the temperature was kept constant to 25◦C. The transmission spectra response of the proposed RH sensor is shown in Figure.3 The excited evanescent waves will interact with the surrounding RH and introduce the change in output spectrum. Also from this Figure, it can be noticed that when the RH increases the transmission spectra shifted towards longer wavelength. The wavelength was shifted from 1543.139 nm to 1550.712 as the RH% increased from 30% to 100% .The sensitivity of the basic SNCS fiber structure (without etching) based RH sensor was 108 pm/RH%. This is due to the fact that, when the light travels from SMF to NCF, the higher order modes would be excited and interfered along the NCF length due to MMI effect. Then, as the RH increases, the surrounding air particles which act as the cladding layer of the sensing region will be occupied by water particles. This leads to an increase in the surrounding refractive index (RI) of the air from 1 towards the water RI of 1.333 [1, 5].

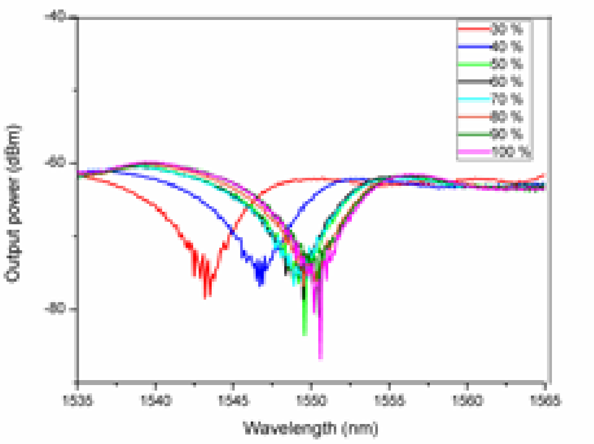
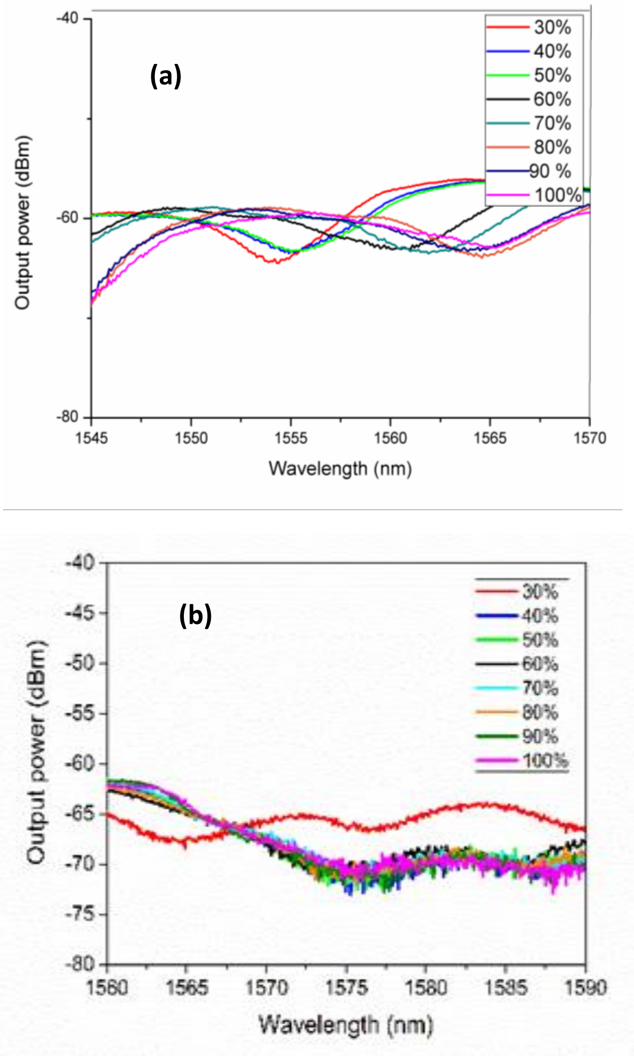


Fig. 3. The transmission spectra response of the OFHS as function of RH with NCF diameter of 125µm.

The etched NCF diameters of the sensor structure of (100, 80, and 60) µm with fixed fiber length were investigated. The transmission spectra response of the etched NCFs with the change of external RH were recorded as shown in Figure. 4(a, b, c). It can be seen that the sensor structure with the diameter of 60 µm shows the larger wavelength shift than that of 125µm basic structure. Figure 5 shows the shift in wavelength of the proposed RH sensor with different NCF diameter versus different RH values. The results indicated that the RH sensitivity was enhanced from 108 pm/RH% to 184.57 pm/ RH% as NCF diameter was reduced from 125 µm to 60 µm. This is may be attributed to the effect of NCF diameter tuning where smaller fiber diameter causes more evanescent waves interaction with the environment humidity [1]. The polynomial fitting coefficient is 0.9395, which shows a good RH sensing characteristic of the SNCS based sensor.



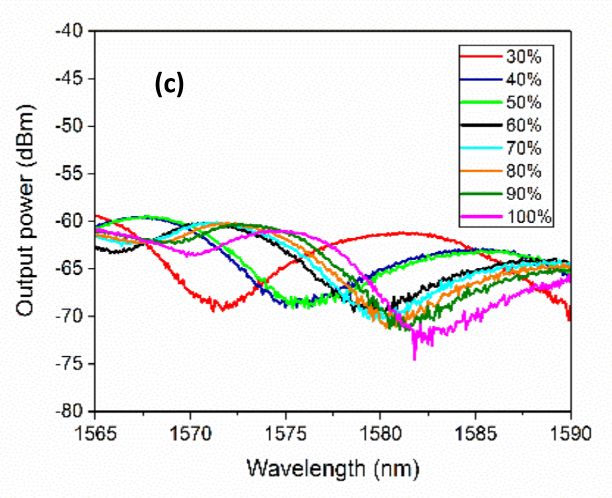


Fig. 4. The transmission spectra response of the RH sensor for different NCF diameter (a) 100 µm, (b) 80 µm and (c) 60 µm.

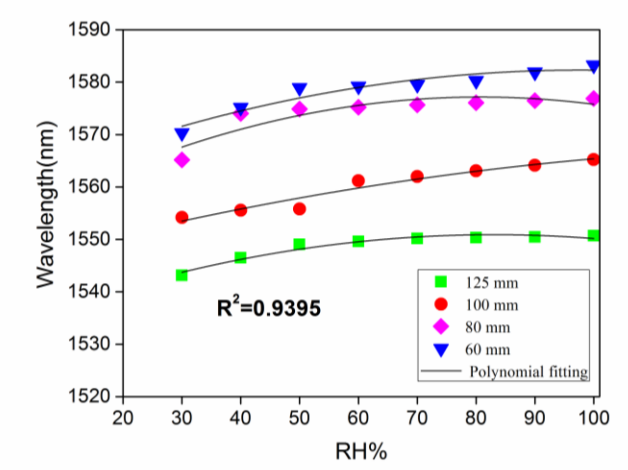


Fig. 5. Wavelength shifts of the proposed RH sensor with different NCF diameter versus different RH values.

Conclusion

In this work, a compact and simple SNCS fiber structure for RH measurements was proposed and demonstrated experimentally. An improved structure to enhance the sensitivity of the sensor was achieved by tuning the NCF diameter. Chemical etching method was used to reduce the NCF diameter from 125 to 60 µm. The obtained results showed that the NCF at 60µm diameter exhibits the highest sensitivity. Our results showed that the proposed sensor structure has a significant potential in RH monitoring.

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متحسس للرطوبة النسبية محسن معتمدا في بناءه على تغيير قطر الليف البصري المنزوع القلب

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الخلاصة: تم بناء متحسس للرطوبة النسبية من تركيبة ليف بصري احادي –ليف بصري منزوع القلب –ليف بصري احادي . تم اختيار اداء هذا المتحسس مع تغيير قطر اليف المنزوع القلب والذي يمثل الجزء الاساس للحساس وزيادة عدد المجالات الهاربة. اختيرت عدت قيم لاقطار الليف المنزوع القلب هي على التوالي (100و80و60) مايكرومتر حيث تم انقاص هذه الاقطار بعملية التأكل الكيميائي بغمر الليف في حامض الهايدروفلوريك بتركيز (40%) . ان اعلى قيمة للحساسية كانت 184,57 بيكومتر/التغيير في الرطوبة النسية في مديات للقراءة من 30% الى 100% عند القطر 60 مايكرومتر وبقراءات واقعية.