New Silica Microspheres Array Sensor

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ABSTRACT

In this work a novel optical fiber sensor based on silica microspheres array is proposed. Different sensing heads are presented and compared, differing on the number of microspheres. These structures, ranging from arrays of one to five, are spliced in series. The sensor is subjected to different physical parameters, such as strain, temperature, refractive index and bending. Depending on the number of microspheres the sensitivities to strain and bending are different. The sensor also presents a high sensitivity to temperature of 20.3 pm/ºC.

Keywords: Optical fiber sensor, microspheres, physical parameters.

1. INTRODUCTION

The use of silica microspheres has attracted attention in fiber sensing over the last decades. In 1995, the first paper on the excitation of a microsphere with external beams was published[1]. There have been reported several ways to couple light into the microspheres. For instance, the use of a prism, produced by the angle polishing of the end face of a fiber[2], or the use of tapers[3] have been studied. All of these configurations take advantage of the whispering gallery modes that are achieved due to the structure geometry.

There are two different ways to produce silica microspheres at the end of a fiber section: through CO_2 laser[3,4] and electric arc discharge produced by a splice machine. The former produces structures with high symmetry, while the last has a lower cost associated, since only a splice machine is required.

In this work, a different approach is done using microspheres produced using single mode fiber. Different sensing heads are produced by splicing microspheres in order to produce an array. The sensing heads are tested to different physical parameters.

2. EXPERIMENTAL RESULTS

The experimental setup of the proposed sensor configuration is shown in Figure 1. The sensor was spliced between the broadband optical source (with a bandwidth of 70 nm and centered at 1545 nm) and the optical spectrum analyzer (OSA). All measurements were done in transmission, with a resolution of 0.2 nm. The dotted microspheres show the possibility of creating an array of multiple microspheres. Also shown in the Figure 1 are the microscope photographs of the several sensing heads tested, with the number of microspheres comprised between 1 and 5.

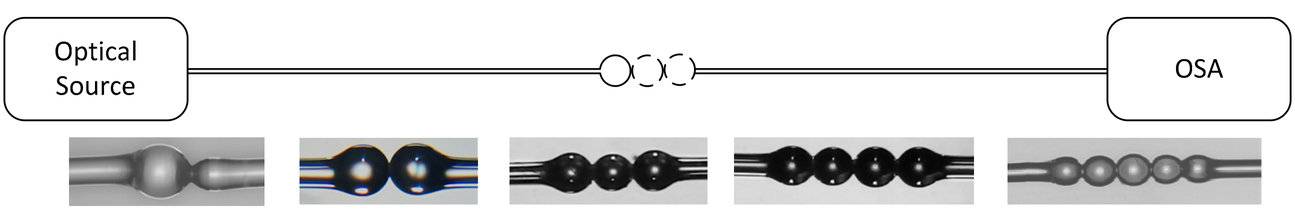

Figure 1.Experimental setup of the microspheres array based sensor. Different microscope photographs are also shown, for sensors with 1 up to 5 microspheres.

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The microspheres were produced by electric arc discharge of a splice machine. All the sensing heads were produced using the manual program of the splice machine. To create such structures, the number of electric discharges was of ~50 and the final diameter was, on average, of 221 µm. The process of manufacturing was simple and very quick. In the case of a single microsphere, it was produced at the end of a single mode fiber (SMF) tip and afterwards spliced to a section of SMF. For the two microspheres sensor, firstly each structure was produced at the end tip of SMF and afterwards the two microspheres were spliced. Above that number of microspheres, the second microsphere was cleaved at its end, and a third microsphere was spliced, and so on. These new structures revealed to be sensitive to several physical parameters, besides being robust and easy to fabricate. The spectra obtained were a result of the reflections occurring at the interfaces of each microsphere with the SMF or the following microsphere. Thus, the higher the number of microspheres, the lower the spectrum visibility attained.

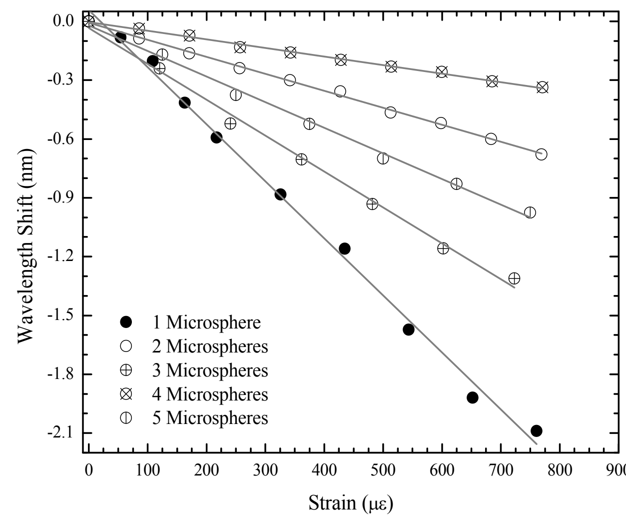

Figure 2.Wavelength shift with the applied strain for five different sensors.

Table 1. Strain sensitivity obtained for each sensor.

# microspheres	Sensitivity (pm/με)
1	-2.49
2	-0.87
3	-1.59
4	-0.44
5	-1.31

Figure 2 shows the experimental results of the multiple sensing heads when subjected to strain. The sensors were placed in a translation stage with a resolution of 0.01 mm. The first structure with a single microsphere presents a sensitivity of -2.49 pm/με and is the most sensitive when subjected to strain. Regarding the remaining ones, a dependence on the number of microspheres is quite clear. For an odd number of microspheres the sensitivity is higher than for an even number of microspheres. These structures can be seen as ball lenses, where focus divergence and convergence occurs, for even and odd number of microspheres, respectively. Table 1 presents the different sensitivities obtained. Besides the wavelength shift, both visibility and intensity increased with the applied strain, for the sensors with a number of microspheres higher than 2. This can be due to a better alignment in the focus points as the fiber is stretched.

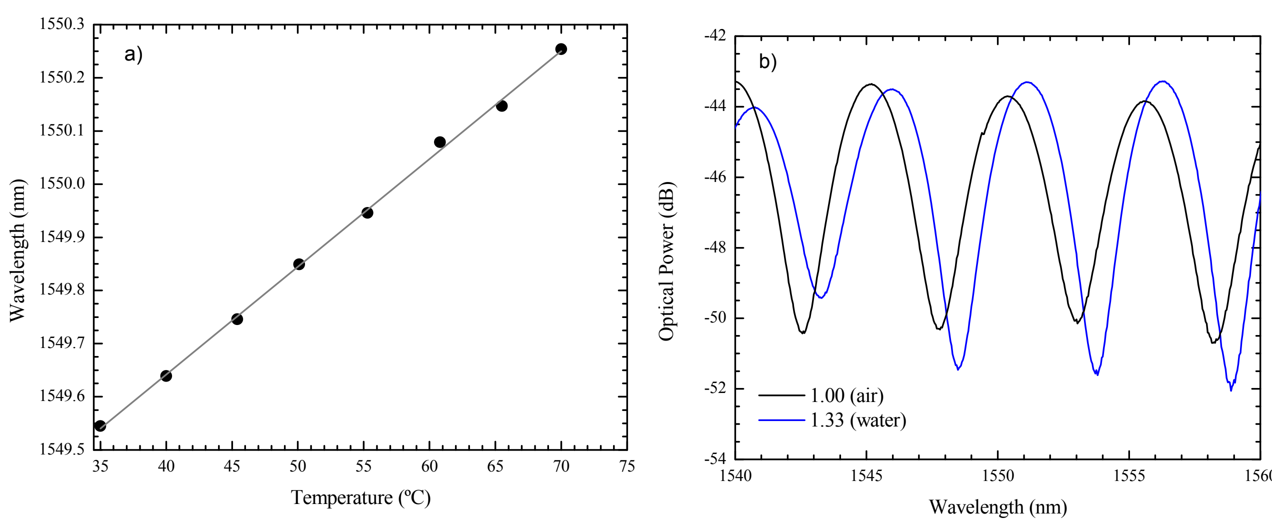

Figure 3. a) Wavelength dependence on the applied temperature for the sensing head with a single microsphere. b) Spectra of the same sensing head both in air (n=1.00) and when submerged in water (n=1.33).

The sensing head with one microsphere was subjected to temperature variations. In order to do that, it was placed in a tubular oven, and measurements were done in a range of 35 ºC, with a resolution of 0.1 ºC. The behavior was linear, as can be seen in Figure 3a, and the sensitivity attained was of 20.3 pm/ºC. Besides, this sensing head was placed in a liquid and proved to be sensitive to refractive index variations, both in wavelength and visibility, as shown in Figure 3b. This result is expected due to the change of the focus alignment between the ball lenses as the refractive index of liquids varies.

Figures 4a and 4b show the results obtained for bending measurements for the single and three microspheres sensors, respectively. In both situations a nonlinear behavior was observed. However, each spectrum can be divided in two linear regions, for lower and higher bending radius. Considering only the lower regions, linear sensitivities of 24.81 pm/m and 45.47 pm/m were respectively obtained for the single and three microspheres sensors. The higher the number of microspheres, the larger the dynamic range of the measurement that can be used to measure bending with a linear behavior. Notice that whilst for one microsphere, the dynamic range was of ~3 m, the sensor with three microspheres presented a dynamic range two times higher (~6 m).

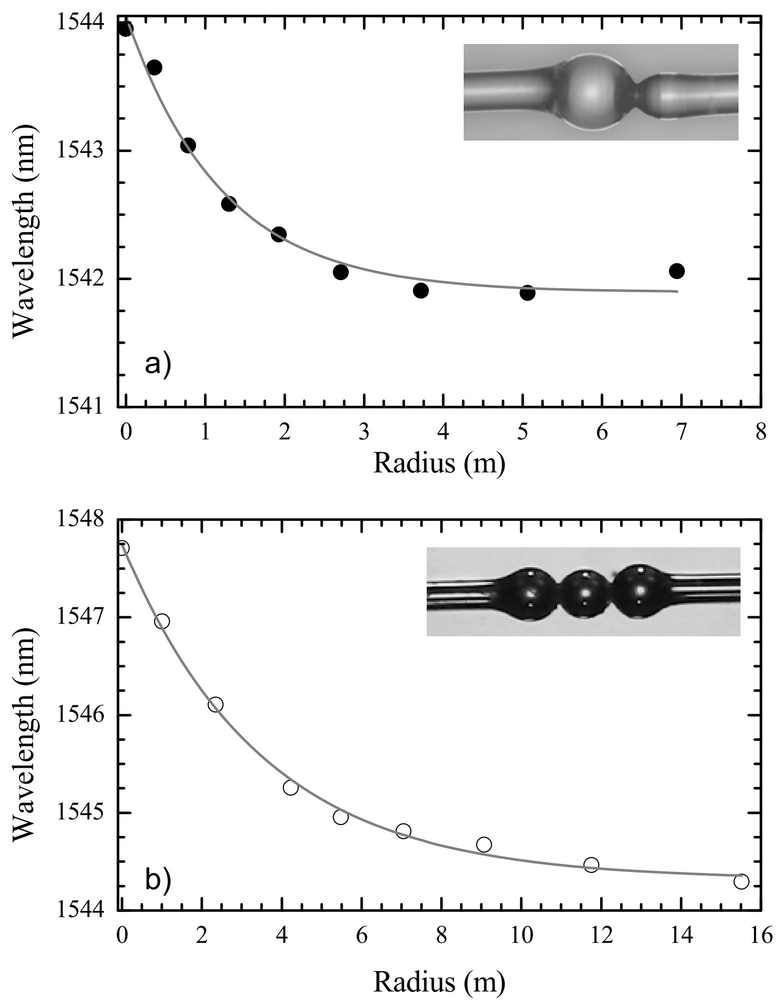

Figure 4. Wavelength dependence bending radius for the sensing head with a) one microsphere and b) three microspheres.

3. CONCLUSIONS

The use of an array of microspheres can provide robust and easy to manufacture optical fiber sensors. In this work different sensing heads were manufactured, with the number of microspheres connected in series ranging from one to five. The sensing heads were subjected to different physical parameters, such as strain, temperature, refractive index and bending. Sensors with an even number of microspheres revealed to be more sensitive to strain than sensors with an odd number of microspheres. When subjected to bending, a nonlinear response was obtained. However, when considering the linear regions, the sensing head with three microspheres was more sensitive than the sensor with a single microsphere.

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