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Intensity based optical fiber sensors for calcium detection

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Two optical fiber sensors are proposed and demonstrated for monitoring calcium concentration in a liquid solution. The first sensor utilizes a bundle plastic optical fiber (POF) as a probe. The system comprises fiber optic transmitter, fiber optic probe which consists of 1000 cores as a receiver, mirror reflection, photodiode detector, lock-in amplifier and computer.The measurementis based on the peak voltage of the output which increases with the calcium concentration of the solution varying from 0 to 2.5%. It is found that the peak voltage of the detector increases with the calcium concentration due to the scattering effects which allow more photons to be collected by the receiver. The sensitivity of the bundled POF based sensor is obtained at 4.321mV/% with a resolution of 0.05%. The second sensor employs a silica microfiber as a probe. The system consists of an amplified spontaneous emission (ASE) light source, microfiber probe and optical spectrum analyzer (OSA). The transmitted light intensity is observed to decrease with the increase in calcium concentration due to the change in the refractive index of the solution. The sensitivity of the second sensor is obtained at 2.4dB/% with a resolution of 0.8%. Both sensors show a good stability and high sensitivity. They are simple in design and low in fabrication cost, which are appropriate for chemical, biomedical, pharmaceutical and process control applications.

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Keywords: Fiber optic, Fiber optic displacement sensor, Calcium concentration, Intensity modulation

1. Introduction

Calcium is one of the most important minerals for the human body. It helps the body form and maintain strong bones and teeth, prevent clotting blood, send and receive nerve signals, squeeze and relax muscles, release hormones and keep a normal heart beat. Detection of calcium level in our body is very important especially in preventing osteoporosis. Recently, the development of various types of optical fiber sensors for calcium detection has been actively pursued in recent years [1-3]. The optical fiber sensors, and in particular plastic optical fibers (POFs) based sensors, are preferable due to their non-invasive nature, immunity to electromagnetic interference, high sensitivity, compact size and low cost [4-7]. The main advantages of plastic optical fibers (POFs) compared to silica fibers include ease of handling, mechanical strength, disposability and easy mass production of components and system. In addition, POF based sensors do not require sophisticated materials and they can operate at room temperature under varying pressure.

In this paper, two POF based sensors are proposed based on an intensity modulation technique for calcium detection. The first sensor uses a bundled multimode POF as a probe which is immersed in a calcium solution. The calcium ions increase the scattering effect, which influences the amount of the light collected by the receiving fiber. The second sensor is based on a silica microfiber probe, which allows the evanescent field of the propagating light to interact with the surrounding calcium solution. The calcium concentration influences the refractive index of the surrounding solution, which in turn affects the loss from the microfiber. Both techniques are expected to offer a simple, reliable and continuous measurement capability.

2. POF based sensor

Fig. 1 shows the schematic diagram of the experimental set-up for the POF-based sensor, which is used to measure the calcium concentration of the solution. The set-up consists of a fiber optic transmitter and receiver, POF probe, flat mirror surface, silicon photo-detector, and computer. A bundled POF probe with a receiving core is used together with a red He-Ne laser source due to its low cost and high reliability. The bundled fiber has a receiving fiber with 1000 cores. The cross-sectional view of the hemicircular bundled fiber is shown besides the container in Figure1. A silicon photo-detector with an effective area of $1cm^2$ is used to ensure an efficient optical directional coupling with the receiving fiber. The detector also has a fast response time, which is suitable for high speed digital data links. The chopper is used in conjunction with a lock in amplifier to reduce the dc drift voltage due to ambient light.

The positioning of the fiber optic probe is accomplished by mounting it on a micro displacement meter, which is rigidly attached to a vibration free table. Light from the fiber optic transmitter (wavelength at 633 nm) is coupled into the transmitting fiber. The signal from the receiving fiber is measured by moving the probe away from the zero point, where the reflective surface of flat mirror and the probe are in close contact. The signal from the detector is converted into voltage and is measured by a lock-in amplifier and computer via RS232 using a Delphi software. The output intensity is measured by changing the position of the fiber optic probe from 0 to 7 mm in a step of 50µm. The measurements are carried out for calcium solutions with concentrations of 0.5, 1.0, 1.5, 2.0 and 2.5%. During the experiment, temperature is kept constant so that error due to temperature variation is negligible.

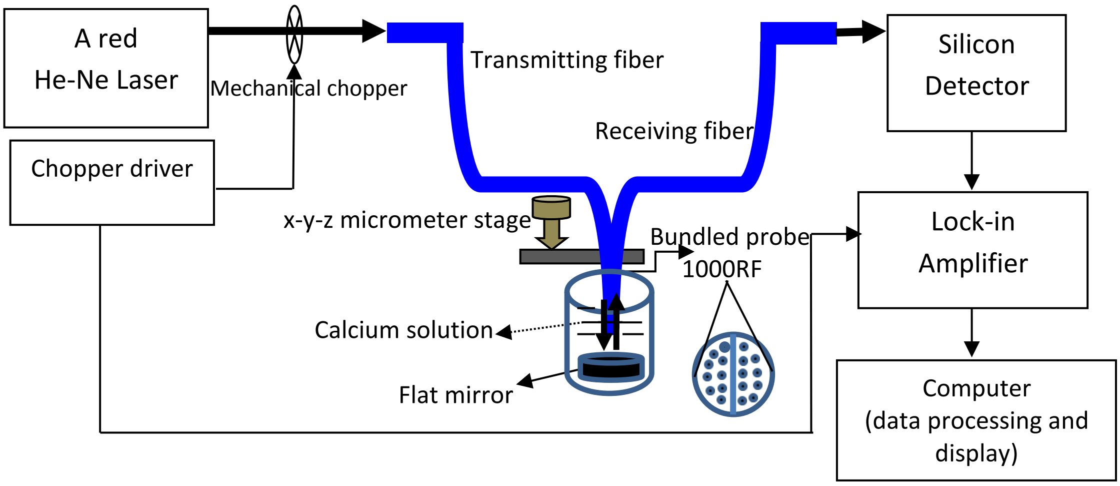

Fig. 1. Schematic diagram of fiber optic displacement sensor with a receiving fiber consisting 1000 cores for calcium detection

3. Silica microfiber based sensor

The microfiber is fabricated using a flame brushing technique where the fabrication setup is illustrated in Figure 2. In the process, a small section of a bare single mode fiber is heated laterally with a suitably designed high-temperature flame using a flame brush technique. Motorized stages are used to pull the fiber during the heating process as well as to move a flame source. The fiber is pulled at a slow pace along their length to form a uniform, smooth and slow taper, which is referred to as a bi-conical, tapered structure. Throughout the process of fabrication, an amplified spontaneous emission (ASE) light source is launched into the input fiber connected to the structure, while the transmitted light is measured by an optical spectrum analyzer (OSA). The optical power of the monitoring signal, exiting from the output fiber port, is constantly recorded in real-time. The process is stopped when the required tapering diameter of around 4 µm is obtained with a low loss signal over the required wavelength range. Figure 3 shows the experimental setup for the proposed microfiber based calcium sensor where the fabricated non-adiabatic microfiber structure probe is immersed in the homogenous calcium solution with different concentration. During the experiment, the error caused by temperature variation is considered negligible as it is kept constant at room temperature.

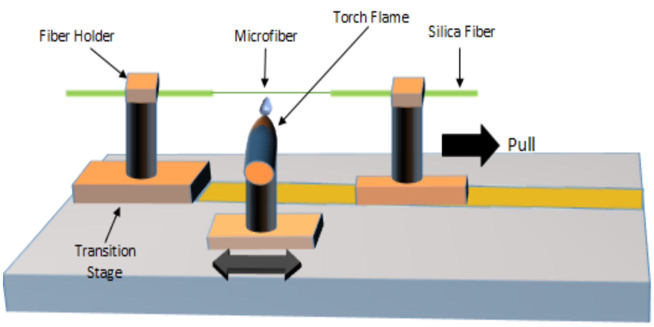

Fig. 2. Schematic illustration of the silica non-adiabatic microfiber fabrication setup

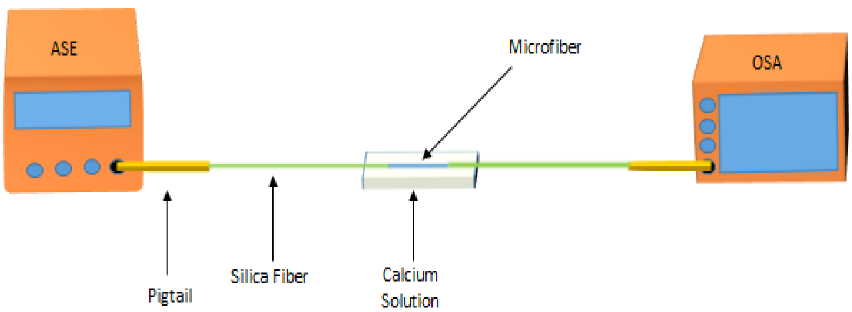

Fig. 3. Experimental setup for detecting various calcium concentrations using a silica microfiber probe

4. Results and discussion

Fig. 4 shows the output voltage against displacement curves generated for various calcium concentrations. All curves exhibit a linear front part with a positive slope before reaching a peak followed by a linear back part with a negative slope. The linear front part of the curve has a steeper gradient while the back part follows an almost inverse square law relationship. At small displacement of front part, the output voltage increases with the displacement due to the increase of the overlapping between the transmitted and received light cone. After reaching the maximum, the output voltage starts to decrease with displacement as indicated in the back part of the curve in Fig. 4. This is due to a large increase in the size of the light cone at the large displacement. The power density decreases with increase in the size of the cone of light at this displacement region. As shown in Figure 4, the peak output voltage increases with the increase of calcium concentration. This is attributed to the calcium ions which increases the scattering of light and thus allows more light to be collected by the receiving fiber's cores especially at larger displacement region.

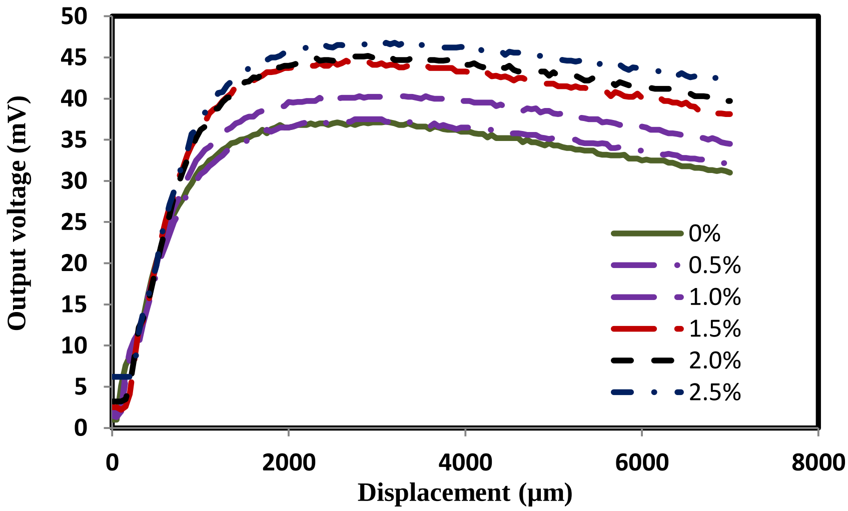

Fig. 4. Output voltage of the sensor (mV) as function of displacement (µm) for various calcium concentration

Fig. 5 represents the shift of the peak voltage against the concentrations of the calcium solution. It is shown that the peak voltage is linearly increases with the calcium concentration with a sensitivity of 4.321mV/%. The resolution of the measurement is estimated to be around 0.05%. The performance of fiber optic calcium sensor using a bundled probe based on peak voltage shift is summarized into Table 1.

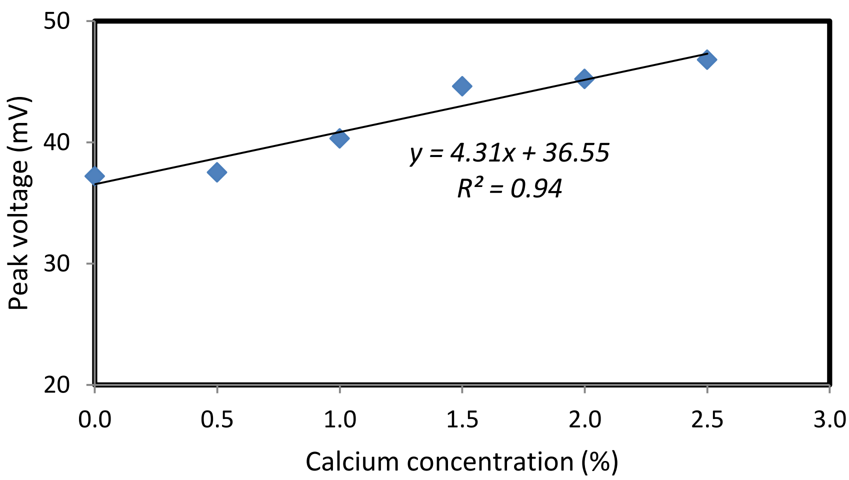

Fig. 5. Peak voltage (mV) as function of calcium concentration (%v)

Table 1. Performance of calcium sensor with fiber bundled probe 1000 RF.

Parameter	Value
Sensitivity (mV/%)*	4.31
Measurement range (%)*	0-2.5%
Linearity (%)	More than 97
Resolution (%)*	0.05

** % volume (%v)*

Fig. 6 shows the experimental result of the microfiber based sensor of Fig. 3 where the output ASE power is observed to reduce with the increase of calcium concentration. This is attributed to the refractive index of the surrounding liquid solution, which increases with the calcium concentration. Inset of Fig. 6 shows the refractive index of the calcium concentration, which increases from 1.333 to 1.347 as the calcium concentration is increased from 0.5% to 2.5%. As can be seen from Fig. 6, the output power of the ASE reduces from -3.21dBm to -8.09 dBm as the calcium concentration is increased from -0.5% to 2.5%. The rate of reduction and linearity are obtained at -2.4dB/% and more than 99%, respectively. The ASE reduction is due to the reduction of index contrast between core and cladding of the microfiber waveguide since the calcium solution functions as an effective cladding of the structure. This reduces the light guiding capability of structure and thus allows more photons to be escaped from the microfiber. The performance of the microfiber based calcium sensor is summarized in Table 2. Both sensors have the advantages of simple measurement, small device, fast response, no reagent contamination, easy to achieve real-time, multi-parameter and simultaneous measurements. In the future, it is expected to apply this chemical sensor into medical measurements.

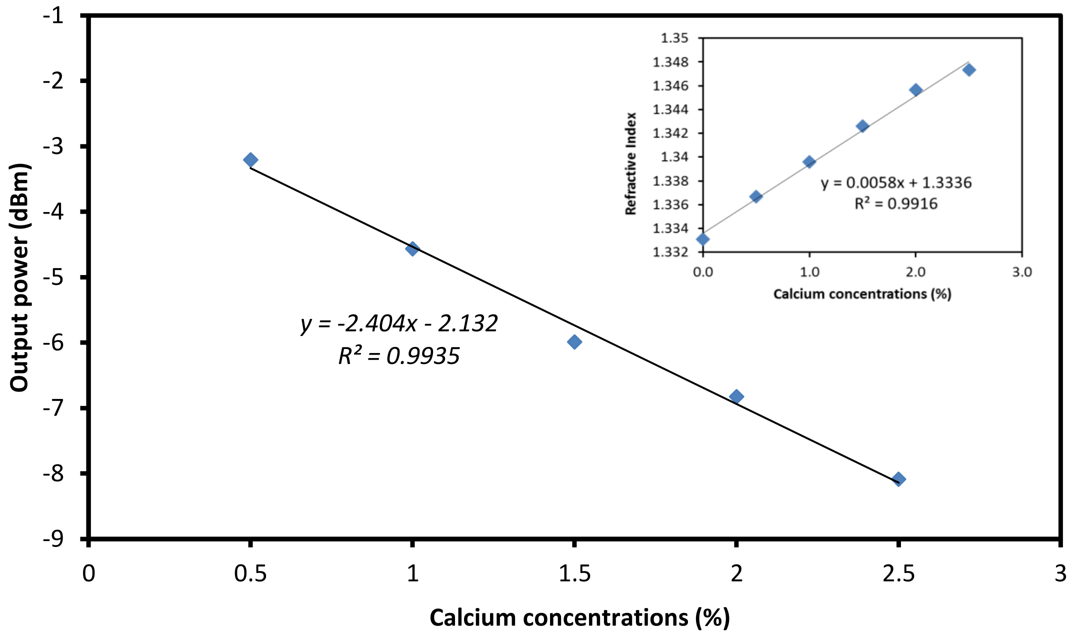

Fig. 6. The output power of the ASE against calcium concentrations. Inset shows refractive index of the solution at different calcium concentrations

Table 2. Performance of the microfiber based calcium sensor

Parameter	**Value**
Resolution (%)*	0.794482
Standard Deviation (dBm)	1.906756
Linearity (%)	99.35
Sensitivity (dB/%)*	2.4
Linear range (%)*	0.5 - 2.5

** % volume (%v)*

5. Conclusion

Calcium concentration measurement has been demonstrated using two approaches: bundled POF and silica microfiber. In the experiment, both sensor probes are immersed into calcium solution which the concentration is varied from 0 to 2.5%. For the POF based sensor, it is observed that the peak voltage of the detector increases with the calcium concentration with a sensitivity of 4.321mV/%. This due to the scattering effects which allows more photons to be collected by the receiving fiber. For the microfiber based sensor, on the other hand, the transmitted light intensity is observed to reduce with calcium concentration. This is due to the refractive index of the solution, which increases with the amount of calcium ion and thus reduces the refractive index contrast between the core and cladding. The sensitivity of the second sensor is obtained at 2.4dB/% with resolution of 0.8%.

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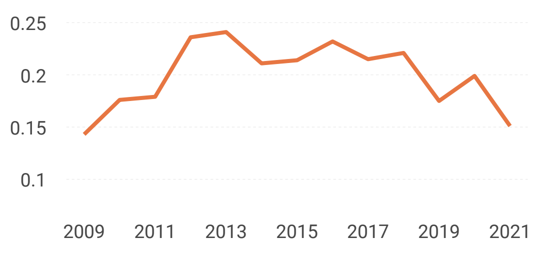

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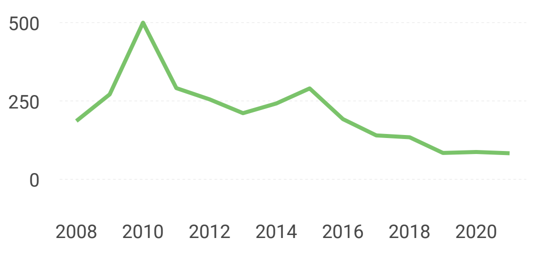

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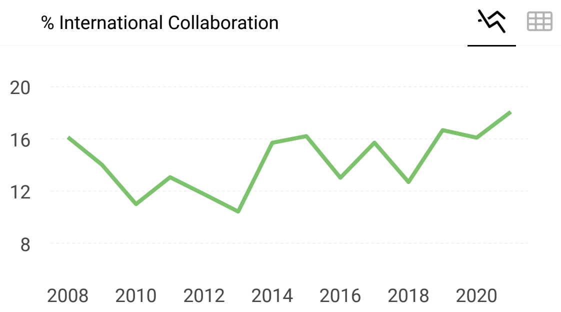

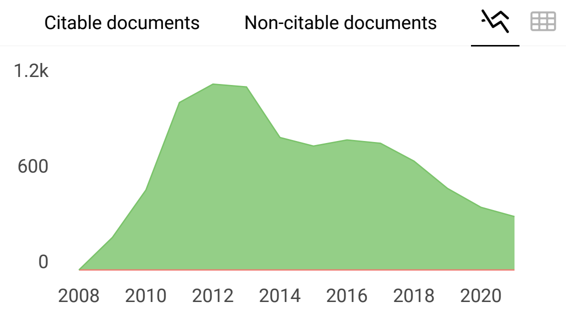

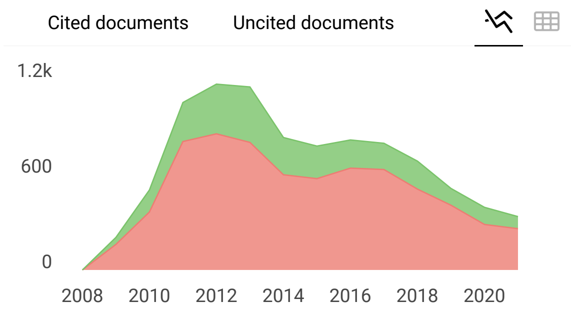

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