A novel optical probe for pH sensing in gastro-esophageal apparatus

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Introduction

Monitoring gastric pH for long periods, usually 24 h, may be essential in analyzing the physiological pattern of acidity, in obtaining information on changes in activity during peptic ulcer disease, and in assessing the effect of antisecretory drugs. Gastro-esophageal reflux, which causes a pH decrease in the esophagus content from pH 7 even down to pH 2, can determine esophagitis with possible strictures and Barrett's esophagus.

One of the difficulties of the optical measurement of pH in the gastro-esophageal apparatus lies in the required extended working range from 1 to 8 pH units [1-3]. Contrary to all acid-base indicators characterized by working ranges limited to 2-3 pH units, methyl red is characterized by a wide working range which fits with the clinical requirements, after its covalent immobilization on controlled pore glass (CPG) [1, 2]. A novel probe design, suitable for gastro-esophageal applications, allows to optimize the performances of the colored CPG. This leads to a very simple configuration characterized by a very fast response time.

Materials and Methods

CPG with pore size of 700 Å were functionalised with γ-aminopropyltriethoxysilane and methyl red was covalently bound by means of amidization, achieved with a solution of p-nitrobenzoyl chloride in chloroform and triethylamine at reflux and with the reduction of the nitro group with boiling sodium dithionite. Sodium nitrite in acidic solution was used for the preparation of diazonium salt. The reactive salt was coupled with the dye in basic water solution. Plastic optical fibres with core diameter of 0.25 (PGR-FB250) and 1 mm (and PGR-FB1000) were used. Figure 1 shows the patented design of the novel fiber tip sensor for pH measurement [3]. Two optical fibre are used, one connected to the optical source and the other one coupled to the photodetector. The distal end of each fibre is cut at an angle capable to assure the total reflection of the optical radiation and the CPG with immobilised methyl red are immobilised on the lateral external surface, by the following procedure used to fix the CPG at the end of the fibres: the plastic fibres were heated up to the softening point (roughly 80 °C) and the CPG were pressed on them in order to form a thin pH-sensitive layer. In this way, the light guided by the input fibre is totally reflected at the end of the fibre, is modulated by pH values crossing the CPG layer and after the total reflection at the second fibre tip is coupled back to the output fibre and sent to the spectrophotometer (Ocean Optics). An halogen lamp is used as optical source.

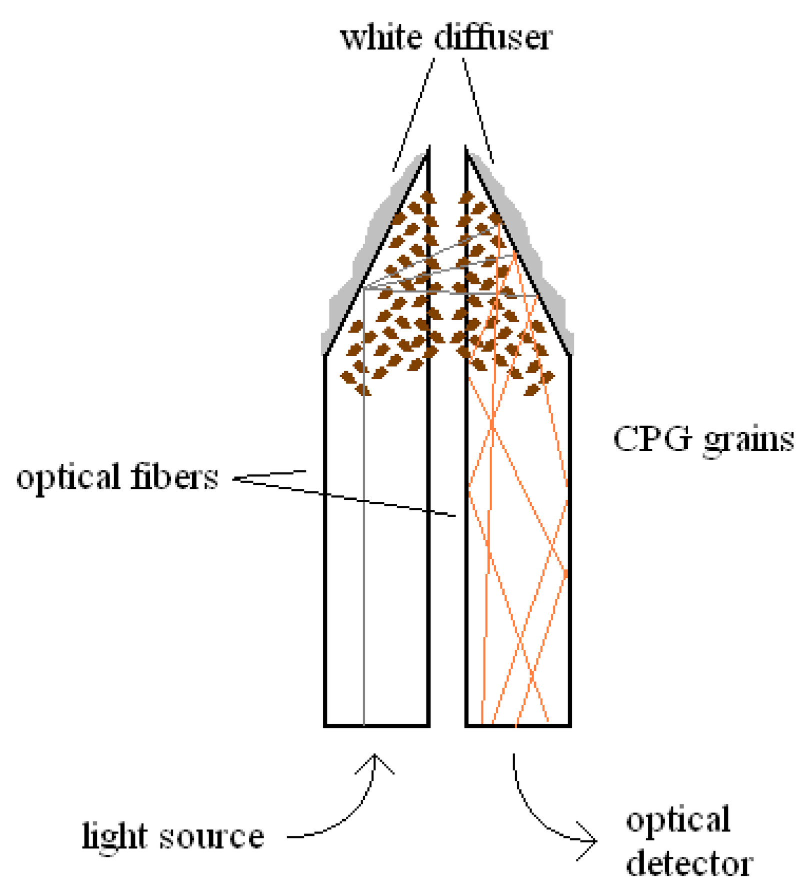

Figure 1. Scketch of the novel configuration fibre tip sensor for pH measurement.

Results and Discussion

Plastic fibres with the external diameter of 1 mm fibre were used in the first realisation of the fibre tip pH sensor. Figure 2 shows the absorption spectra for different pH values in the range. The absorption around 550 nm increases with a decrease of pH with a slight blue shift of the peak. The zero baseline corresponds to pH value of 9.48, a pH value in which the absorption at 550 nm is minimum.

Figure 3 shows the calibration curve achieved considering the value of the absorbance at 545 nm as a function of pH. The circles are the experimental point whereas the continuous line is the sigmoidal curve given by the following equation:

$$S = S_0 + \frac{a}{1+\exp\left(-\frac{pH - pK}{b}\right)}$$

S is the difference of the absorbances measured at 545 nm and 700 nm, pK is equal to -log K, where K is the dissociation constant of the immobilised indicator, and S_0, b e a are constant values.

The working range of the pH probe covers the required pH range between 1 and 8 pH units with a linear relationship between 2 and 4.5 pH units. The precision of the probe in the linear range can be estimated in 0.04 pH units, on the basis of the signal/noise ratio observed in the absorption spectra.

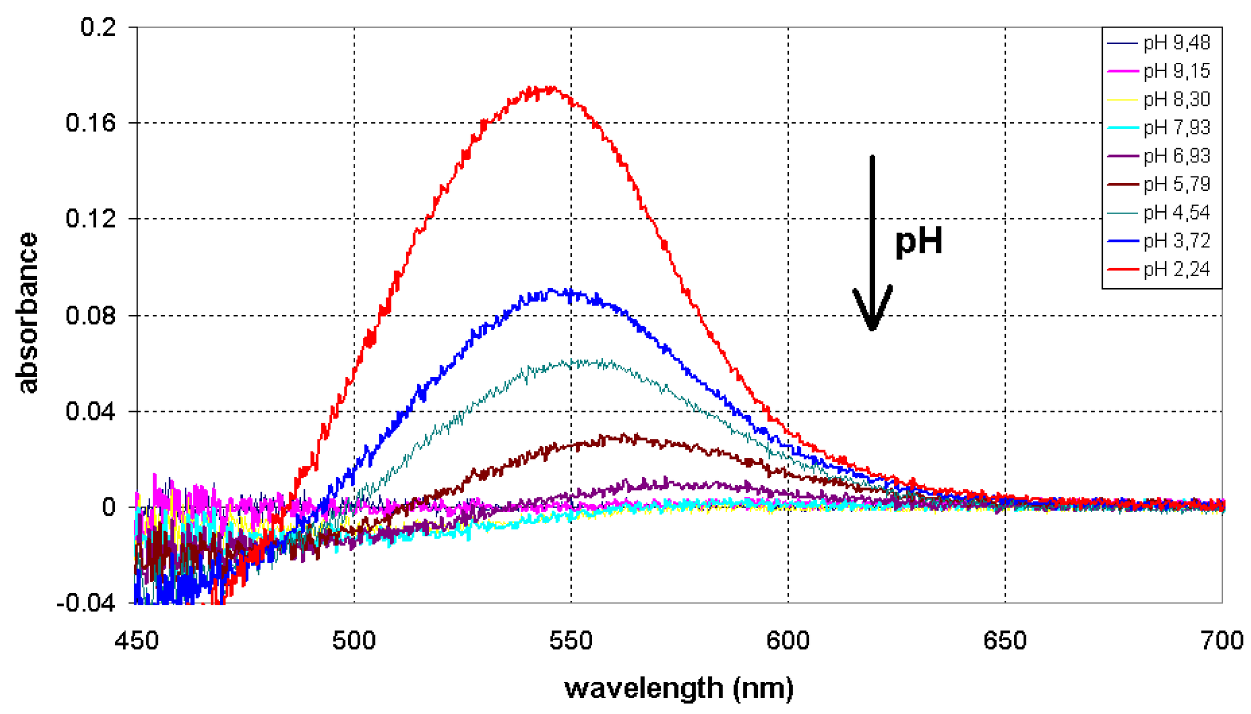

Figure 2. Absorption spectra achieved with the probe shown in Figure 1 (fibre diameter: 1 mm).

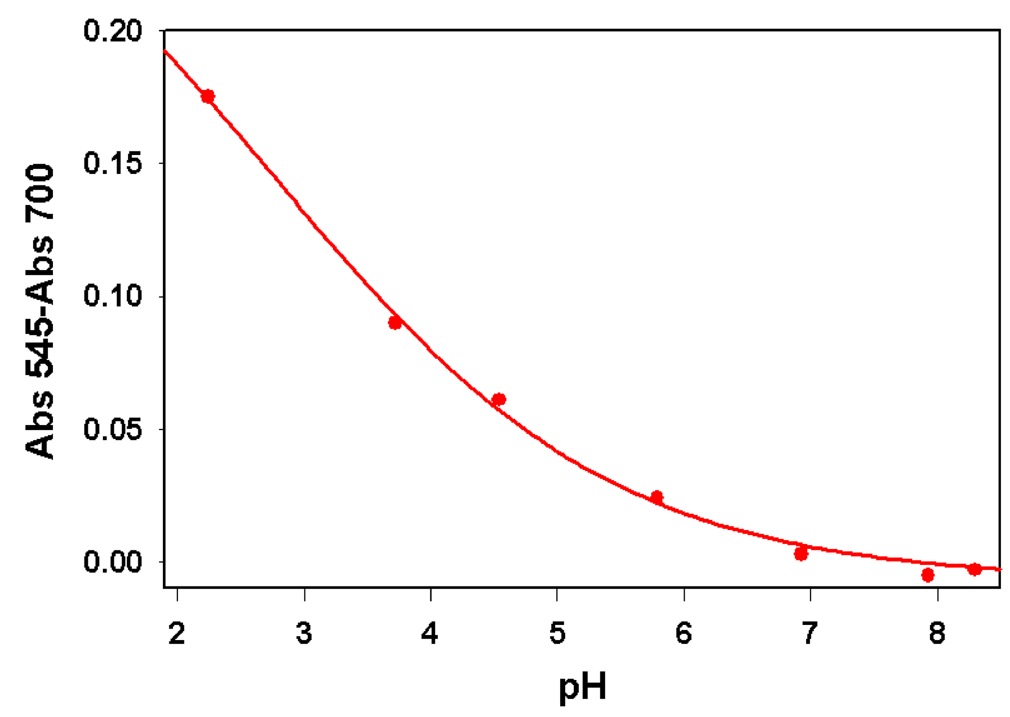

Figure 3. Calibration curve of the pH probe.

On the same basis, the precision is ≤ 0.08 pH units in the range 4.5-6, whereas in the range 6-7.5 the precision is ≤ 0.15 pH units. At this point, it is noteworthy to point out that the required accuracy of 0.1 pH units mentioned in the introduction should be reached mainly around the pH value of 4, which is considered the traditional threshold below which the esophageal pH is considered harmful.

As a matter of fact, the use of plastic optical fibers with 1 mm diameter, implies an overall diameter of the probe ≅2 mm, which is too large for in-vivo applications, especially in view of its combination with the measurement of other parameters. Therefore, a reduction of the probe dimension is mandatory in order to arrive to the realization of a miniaturized optical fiber pH probe suitable for in-vivo measurements in the gastro-esophageal apparatus. On the basis of these considerations, smaller fibers with a diameter of 250 µm were used. Figures 4 and 5 shows the absorption spectra and the response curve achieved with this miniaturised probe.

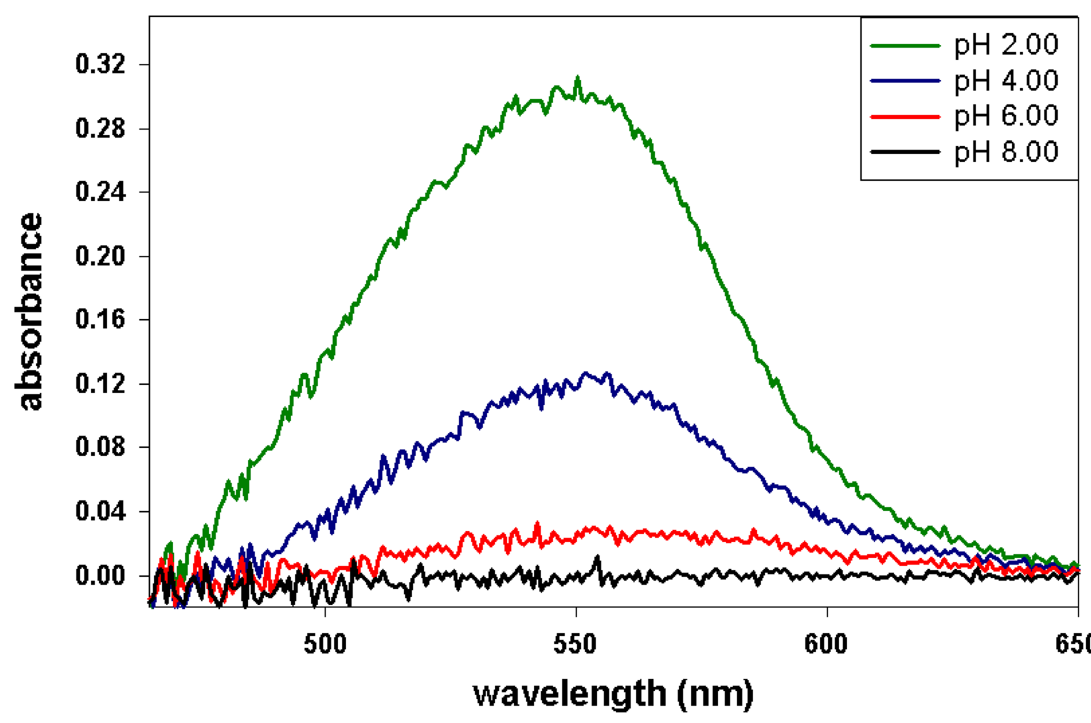

Figure 4. Absorption spectra achieved with the probe shown in Figure 2 (fiber diameter: 250 µm).

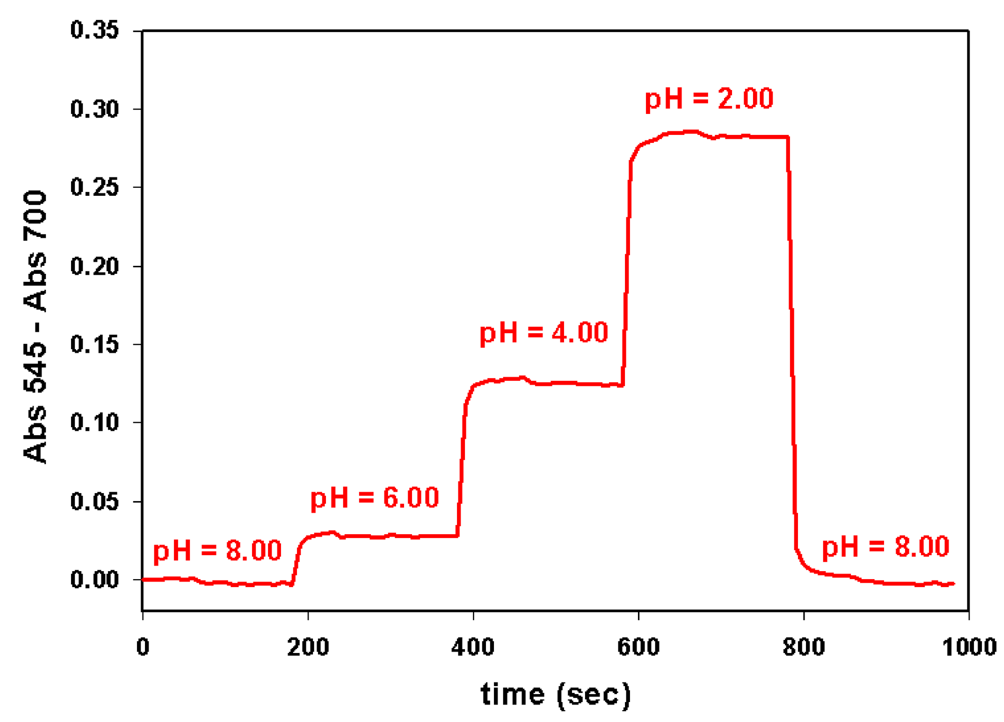

Figure 5. Response curve of the optical probe sensor for different pH steps.

Conclusions

A novel optical fibre probe for pH detection was designed and characterised in the lab, in view of in vivo applications in the gastrooesophageal apparatus. The range of clinical interest is quite well covered with the use of a single pH indicator, methyl red. It should be said that the linear relationship occurs only in the 2-5 range, which implies the adoption of a three point calibration curve for the final use of the sensor. On the other hand, the fast response time of the sensor, of the order of 30 second or less, makes this procedure practicable in short time.

References

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