CORROSION PREVENTION BY DETECTION OF CORROSIVE LIQUIDS USING OPTICAL FIBRE SENSORS

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INTRODUCTION

Corrosion caused by liquids rapidly changes the surface properties of components in engineering structures, and that will finally endanger the functionality of the structural part. However, if there exist monitoring technology providing continuous information on the presence of corrosive liquids, corrosion treatment and even corrosion prevention can start at a very early stage. The basic idea presented in this paper is to detect corrosive liquids by extended optical fibres sensors. Surface plasmon resonance offers the possibility to detect liquid contaminants at the surface of the optical fibre in a quantitative and even analytical way.

The use of optical fibres in sensing technologies is one of the most interesting upcoming technologies. Their application is related to a number of advantages, such as the small size of the sensor, the flexibility in sensor design, the inertness concerning electro-magnetic interferences, etc.. Optical fibre sensors have a small diameter which is typically in the range of 0.2 – 0.6 mm. This frequently solves spatial problems if only limited space is available. Moreover, optical fibres can work in a range up to kilometres, enabling an extended sensing area. The detection of corrosive liquids (or at least of just liquids) is possible by surface plasmon resonance which occurs on the surface of uncladded optical fibres if an appropriate metal coating is present. The set-up is relatively easy to implement, and the system is inert to electromagnetic interferences.

An optical sensor is a device converting the quantity measured to another quantity characteristic for a light wave [1]. The sensitivity can essentially be enhanced by functional coatings (see e.g. [2]). For practical monitoring applications, miniaturization is required for the light source and for the read-out unit. Furthermore, the stability of the baseline still needs be determined.

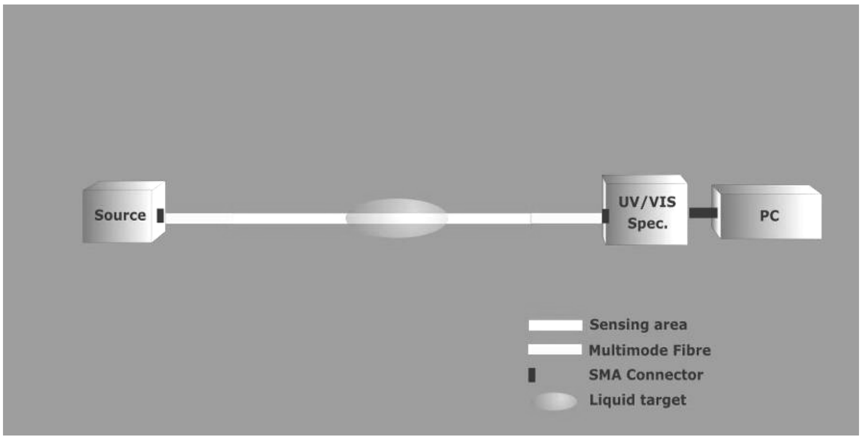

Figure 1 Set-up for surface plasmon resonance measurements with extended optical fibre sensors for corrosive liquid detection.

The principle of surface plasmon resonance [3] is relatively easy to understand (Figure 1 and Figure 2). When an optical waveguide is covered by a metal layer of appropriate thickness, and if this layer is in contact to a dielectric material of a certain refractive index, the light propagating in the waveguide will come into resonance with surface modes of the electromagnetic waves propagating in the metal layer. The appropriate thickness is typically in the range between 50-70 nm.

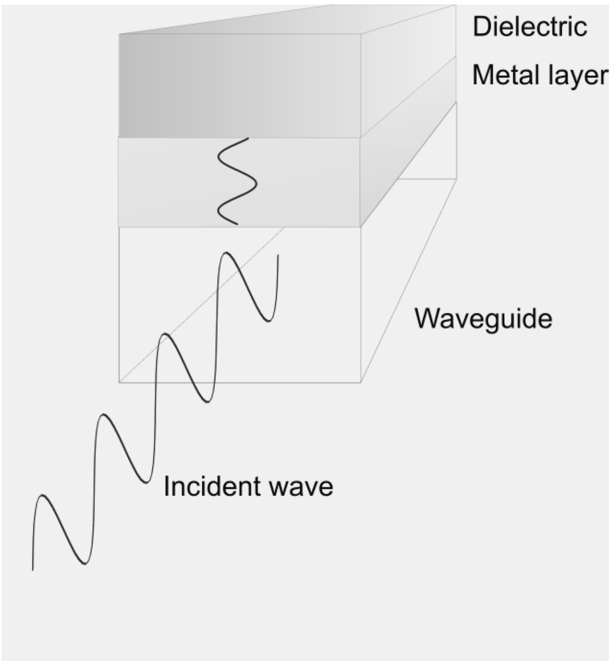

Figure 2 Surface Plasmon Resonance

Optical fibre sensors based on SPR offer interesting possibilities, especially with respect to difficult sensor positions. In some cases, there is almost no space available for bulky sensors and therefore, only the implementation of tiny, but extended sensors is feasible. A possible field of application might be the floor under the galley area of airplanes where spilled liquids can cause severe corrosion of floor beams and seat tracks. Therefore, the optical fibre in the research presented was exposed to various liquids that are known to be responsible for corrosion of the floor beams, like cola, coffee and soup. Clear absorption signals were recorded indicating the ability of the sensor to detect those liquids. Lab experiments conducted led to key results engaging the further implementation of SPR optical fibres sensors in this particular application.

In this research, multimode optical fibres made of glass or polymer were used and at the sensing part, the jacket and the cladding were removed so that the core was exposed. On the core, a gold film was deposited having an appropriate thickness. The detected liquid is in direct contact with the metal layer. The light ray is transmitted in the multimode optical fibre and will experience numerous reflections over the length of the SPR sensing element enhancing the detection sensitivity. The optical fibre thus allows analyzing the signals arising from multiple reflections enhancing the signal-to-noise ratio.

MATERIALS AND METHODS

A halogen and deuterium light source (AvaLight-DH-S, Avantes, Eerbeek, The Nederland) were used to obtain a broadband light signal in the UV/VIS/NIR range. A patchcord with SMA connectors (Avantes, The Nederland) transports the light towards the sensor probe. The optical fiber sensor is made from multimode fiber with diameter of 400 μm and a numerical aperture of 0.39 (TEQS^{TM-} Thorlabs, Munich, Germany). The sensing part is an uncladded optical fibre with a gold coating applied by sputtering. The transmitted light is collected by a spectrometer with a detection range from 200 nm to 1100 nm (UV/VIS Fiber Optic Spectrometer AvaSpec 2048 – Avantes, , Eerbeek, The Nederland). The set-up to proof the principle of detection is depicted in Figure 3, left.

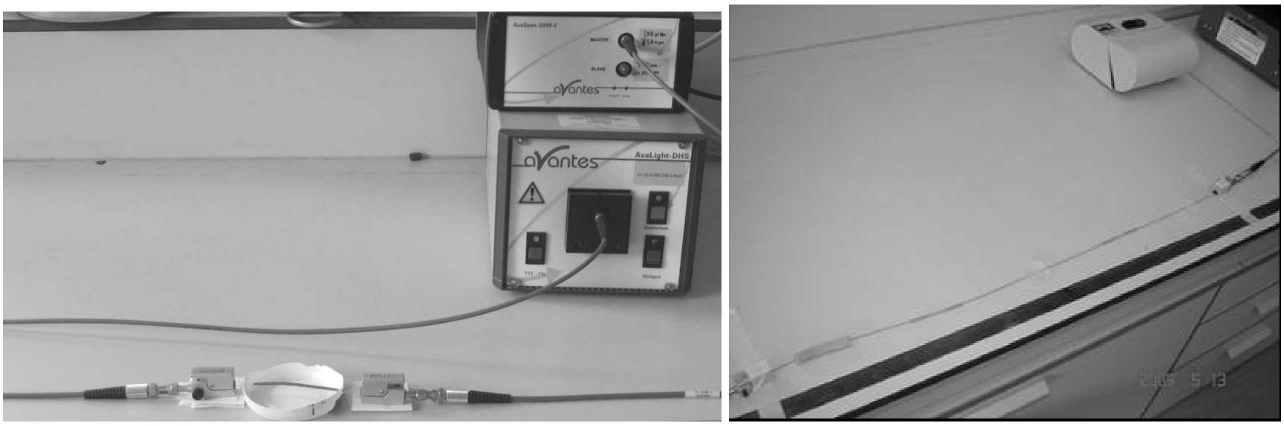

Figure 3 left) The sensing part of the optical fibre sensor is protected by a perforated tube, right) "long fibre" sensor set-up with different sensing spots

In order to extend the optical fibre to larger sizes, an optical fibre sensor with a length of about 1 m was equipped with three different sensing areas having a respective length of about 2 cm (Figure 3, right). Under these areas, small vessels were present containing the target liquids. The obtained signals is approximately additive with respect to the separate contributions.

An extended optical fibre that is completely uncladded shows low mechanical performance. Therefore, the fibre is protected by a polymer tube. In our case, a perforated shrinking tube was used (Figure 4).

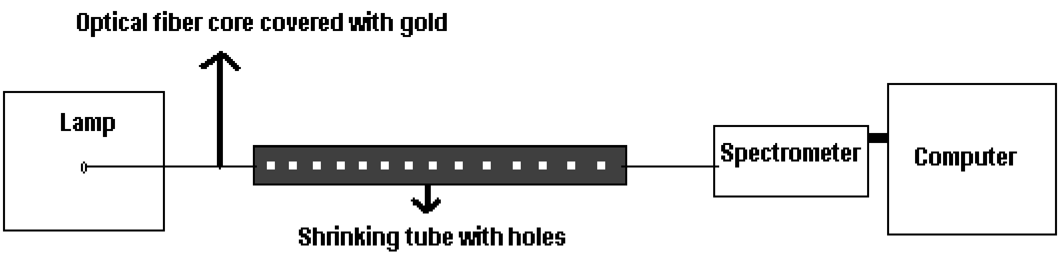

Figure 4 Shrinking tube for protecting gold layer and reducing fragility

RESULTS AND DISCUSSION

With the first set-up, the feasibility to determine the amount of contaminants could already be proven. The results of the measurements are depicted in Figure 5. It is clear that different liquids show different resonance patterns that derive from differences in the refractive index.

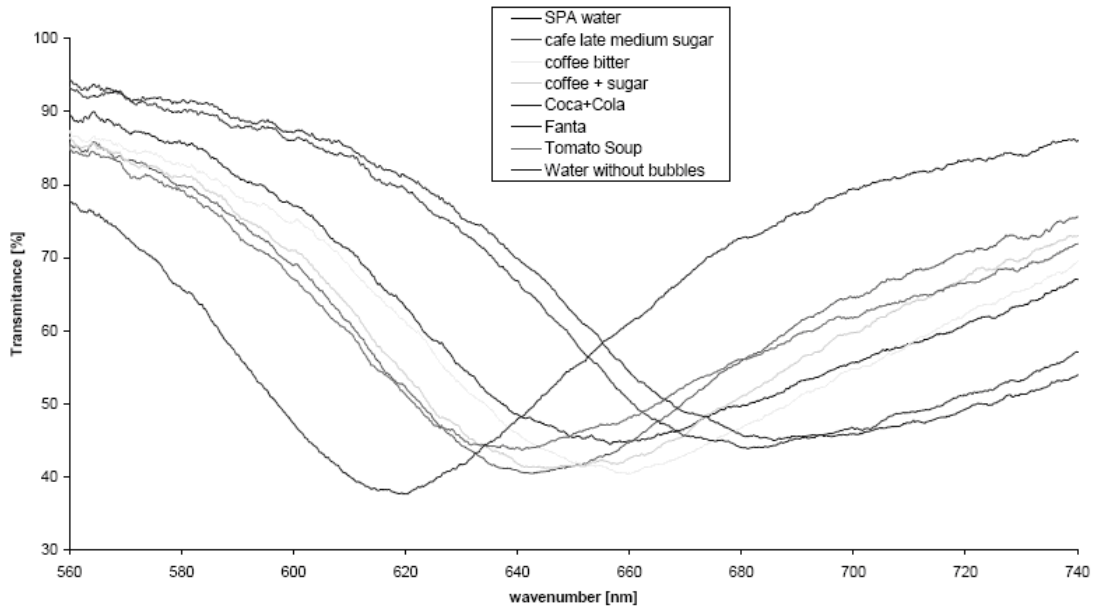

Figure 5 Spectra recorded for different relevant liquids

The shrinking tube is used for both protection of the gold area and also for reducing the fragility of the fibres. The holes allow the liquid to reach the sensing area. The idea of the measurement is quite simple. If there is a resonance present in the optical transmission signal, the gold layer must be covered with matter of a certain refractive index – indicating the presence of liquid. If the experimental conditions are accordingly selected (protecting membranes e.g.), the occurrence of resonance will only happen if a liquid film covers the gold layer. If the wavelength of the plasmon resonance can be determined it will give an estimation of the nature on the nature of the liquid, i.e. cola or coffee could be easily distinguished when the signal is not saturated (Figure 5).

The fragility of the optical fibres made of glass makes it necessary to change to polymer optical fibres. The principal set-up will not change and the lower performance in light attenuation will be overcompensated by the gain in mechanical stability.

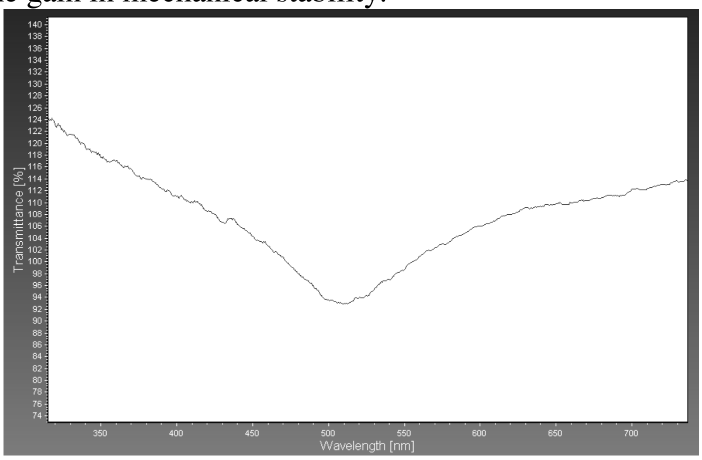

Figure 6 Spectra obtained with polymer optical fibre protected by a perforated shrinking tube

When different liquids on different spots influence the signal at the same time, a superposition of the signal was measured. Furthermore, the intensity of the signal is an estimate of the extent of contamination. In practical applications however, one could expect that big amount of contaminations will make that a part of the spectrum is saturated. But this technology is especially targeted to determine the presence of liquids in general. The detailed nature of the liquids and their precise location is mostly not of importance since it must anyway be considered as a contamination. In this sense; a positive signal indicates that the liquid is present at the location of the fibre and so the liquid has to be removed.

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