# Multiple wavelength SPR sensor analysis

Hamish R. Colenso[1*], Gideon J. Gouws[1], Ciaran P. Moore[2]
[1] Victoria University of Wellington, Wellington, New Zealand
[2] University of Canterbury, Christchurch, New Zealand
* hamish@ecs.vuw.ac.nz

TE WHARE WĀNANGA O TE ŪPOKO O TE IKA A MĀUI
VICTORIA UNIVERSITY OF WELLINGTON

## Abstract

Surface Plasmon Resonance (SPR) sensors based on Gold thin films are typically illuminated by 633 nm laser sources. In this work we investigate illuminating SPR sensors with longer wavelength lasers. We use a model based on Fresnel's equations to achieve this. We also investigate the ability to use a single thickness of Gold film for interrogation over multiple laser wavelengths.

## Introduction

Surface plasmon resonance (SPR) sensors can use the Kretschmann configuration where a metal film is deposited onto a prism, as illustrated in Fig. 1. A laser is shone onto the prism, shown by the black line, and the reflected light intensity can be recorded. A typical reflectance response is illustrated in Fig. 2.

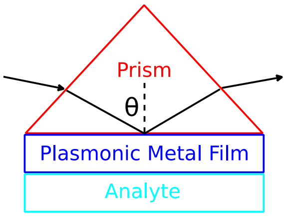


**Figure 1**

Above the critical angle, $\theta_{critical}$, the measured reflectance drops over a narrow angular range due to SPR. The angle at which this drop occurs, as well as the rate of change of the reflectance, and the minimum reflectance observed, are all dependent on the refractive index of the analyte. Therefore, changes in the medium surrounding the sensor can be readily detected by careful observation of the reflectance of the sensor.

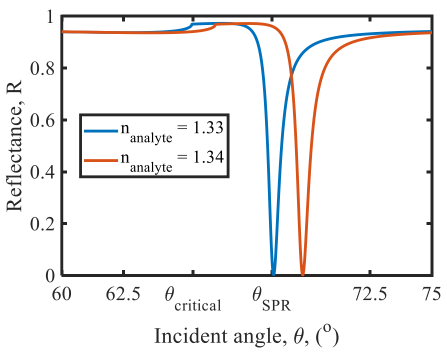


**Figure 2**

We use Fresnel's equations based on [1] to model the changes in analyte refractive index. For a laser light source incident at an angle, theta, normal to the interface between the prism and the plasmonic metal film, as shown by the black line in Fig. 1, the fraction of incident power reflected, R, is given by

$$R = \left| \frac{Z_{in,metal} - Z_{prism}}{Z_{in,metal} + Z_{prism}} \right|^2$$

where $Z_{in\ metal}$ is the wave impedance of the interface between the prism and the metal, while $Z_{prism}$ is the wave impedance of the prism medium. For this work, water is used as the analyte. A notional maximum analyte refractive index change, $\Delta n_{max}$ of 0.01, indicative of a water-glycerol mixture [2] is used to imitate contaminants in the water.

## Sensor characterisation

A sensor reading is defined as the difference in reflectance value, ΔR, when the analyte refractive index is increased by Δn. That is

$$\Delta R = R\,(n_{water} + \Delta n) - R(n_{water})$$

Where $R(n_{water} + \Delta n)$ is representative of the water-glycerol mixture and $R(n_{water})$ is the reference value without any environmental change. If the reflectance values obtained in Fig 2 are used as an example, the sensor reading would be the difference between the red and the blue lines, shown in Fig. 3.

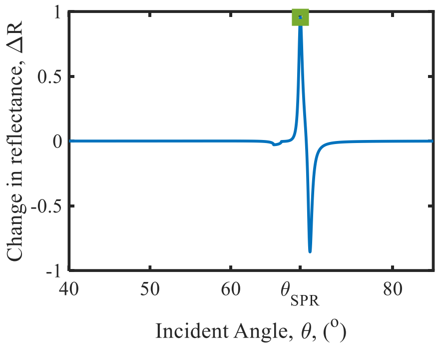


**Figure 3**

To obtain SPR measurements quickly fixed angle laser and detector measurements are commonly used. The incident angle, θ, which produces the maximum sensor reading ΔR, the green square of Fig. 3, is selected as the fixed angle for our model to use. $\theta_{SPR}$ is the incident angle that provides a maximum ΔR value for a refractive index change between 0 and $\Delta n_{max}$. $\Delta R(\theta_{SPR})$ is indicated by the green square on Fig. 3.

$\Delta R(\theta_{SPR})$ is dependent on the thickness of Au thin film used for the sensor. The thickness dependence is illustrated in Fig. 4 for wavelengths between 635 and 904 nm. It is observed that a 53 nm Au thin film produces the highest average $\Delta R(\theta_{SPR})$ response.

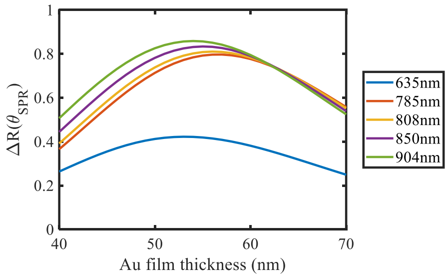


**Figure 4**

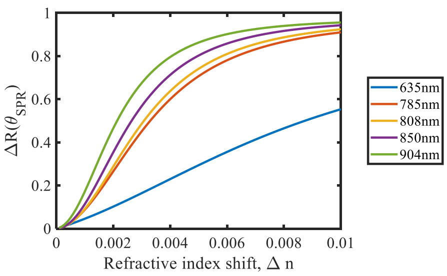


**Figure 5**

Figure 4 only indicates the sensors maximum desired response based on our notional maximum refractive index change of 0.01. Figure 5 shows the sensors entire $\Delta R(\theta_{SPR})$ response range from 0 to $\Delta n_{max}$.

The areas where the sensor changes rapidly, between a Δn of 0 and 0.004 on Fig. 5, is interesting. The area of maximum change in Fig. 5 is investigated by plotting the derivative of $\Delta R(\theta_{SPR})$ with respect to Δn, denoted S, which is illustrated in Fig. 6

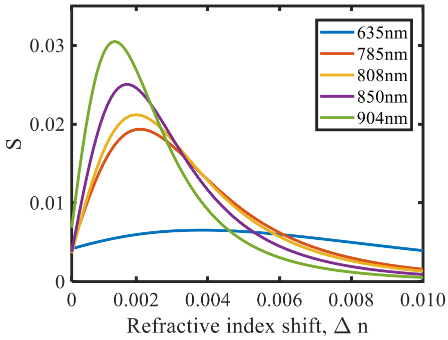


**Figure 6**

The maximum, $S_{max}$, and the full width half maximum, $S_{fwhm}$, of Fig. 6 are of interest. A large $S_{max}$ indicates the sensor has a more pronounced sensitivity to Δn. A large $S_{fwhm}$ indicates that the sensor has a large Δn range over which it is sensitive. Figure 7 provides an indication of the trade off between sensitivity and Δn range for a 53 nm Au thin film sensor at a number of different wavelengths between 325 and 1550 nm.

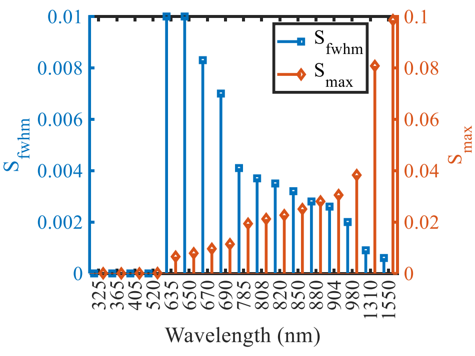


**Figure 7**

## Conclusion

In this work, we have shown that by adjusting the thickness of an Au thin film we can optimise a sensor over multiple wavelengths. For a sensor modelled to detect contaminants in water, the sensitivity of the sensor is larger at long wavelengths but the Δn range of this sensitivity is small. Conversely, the sensitivity is smaller at short wavelengths but the Δn range is longer. This work raises the possibility of using many wavelengths to increase the performance of SPR sensors for water safety treatment monitoring.

## Acknowledgements

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[1] A. Kolomenski, A. Kolomenskii, J. Noel, S. Peng, and H. Schuessler, "Propagation length of surface plasmons in a metal film with roughness," Appl. optics **48**, 5683–5691 (2009).
[2] V. Kravets, R. Jalil, Y.-J. Kim, D. Ansell, D. Aznakayeva, B. Thackray, L. Britnell, B. Belle, F. Withers, I. Radko *et al.*, "Graphene-protected copper and silver plasmonics," Sci. reports **4**, 5517 (2014).