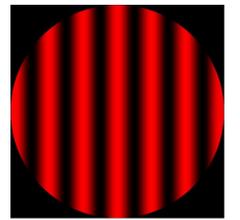# Sensing of liquid analytes via the phase shift induced by surface plasmon resonance

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Abstract

A spectral interferometric technique to detect the phase shift induced by surface plasmon resonance (SPR) in the Kretschmann configuration is used in sensing small refractive index changes in a liquid analyte. The technique employs a polarimetry setup with an SPR structure comprising an SF10 glass prism, an immersion oil and a gold coated SF10 slide with an adhesion layer of chromium (see Fig. 1). The polarimetry setup is employed to measure the spectral phase shift for aqueous solutions of ethanol. In addition, the phase shift is measured at a specific wavelength as a function of the analyte parameter, and the sensitivity is determined. The measurements are accompanied by theoretical modeling of the spectral phase shift induced by SPR using the material dispersion characteristics, i.e., the refractive index dispersions of the SF10 glass, chromium, gold, and the analyte.
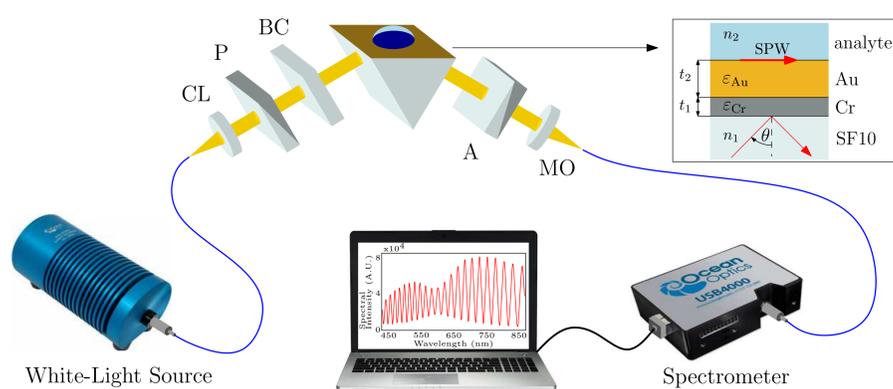
1. Experimental setup

Figure 1: *Experimental setup consisting of collimating lens (CL), polarizer (P), birefringent crystal (BC), analyzer (A) and microscope objective (MO). SPR structure is shown in the inset.*

2. Theoretical results

Reflectance and phase state of a reflected s- and p-polarized light wave are related to the complex reflection coefficient $r_{s,p}(\lambda) = \sqrt{R_{s,p}(\lambda)} \exp[i\phi_{s,p}(\lambda)]$, where $R_{s,p}(\lambda)$ is reflectance and $\phi_{s,p}(\lambda)$ is phase change on reflection. Spectral phase shift is expressed as

$$\Delta_{\mathrm{SPR}}(\lambda) = \Phi(\lambda) - \Phi_{\mathrm{ref}}(\lambda),$$

where $\Phi(\lambda) = \phi_s(\lambda) - \phi_p(\lambda)$ is the phase shift between s- and p-polarized components for analyte, when SPR occurs, $\Phi(\lambda)$ is the reference phase shift, when SPR effect does not occur. To describe reflection in the spectral range, the model uses dispersion characteristics of the materials in the SPR structure. Angle of incidence is approximately 60 °.
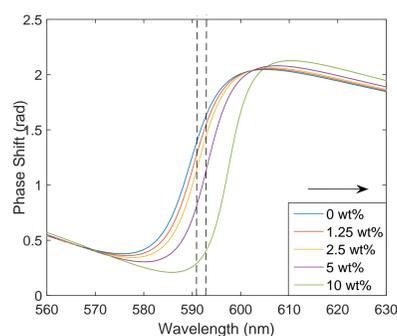

Figure 2: *Theoretical spectral phase shifts for analytes with different weight concentration of ethanol in water. Wavelengths used for sensing are marked by dashed lines.*
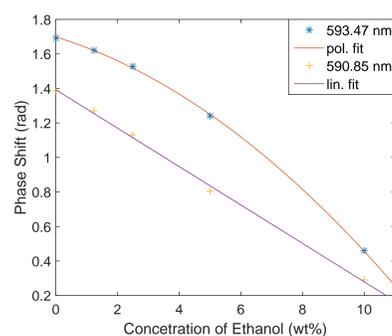
Figure 3: *Spectral phase shift dependence on weight concentration of ethanol in water at two different wavelengths.*

At one specific wavelength, differences of the spectral phase shifts for different analytes are the most significant. It is possible to specify the dependence of the phase shift value on some analyte parameter, as shown in Fig. 3. In this case, parameter of analyte is weight concentration of ethanol in water and wavelength is $\lambda_1 = 593.47$ nm. At another wavelength ($\lambda_2 = 590.85$ nm), the trend is more linear, which is advantageous for sensing.

3. Experimental results

Two channeled spectra for each type of analyte are recorded to measure the spectral phase shift [1, 2] in the experimental setup shown in Fig. 1. One spectrum is for analyte, when SPR effect occurs, and the other one is reference spectrum for air, when SPR effect does not occur. Two such spectra (analyte is ethanol with concentration of 10 wt% diluted in water) are shown in Fig. 4. The visibility decrease is due to the SPR phenomenon. The spectral phase shift $\Delta_{\mathrm{SPR}}(\lambda)$ is determined using the Fourier transform analysis.
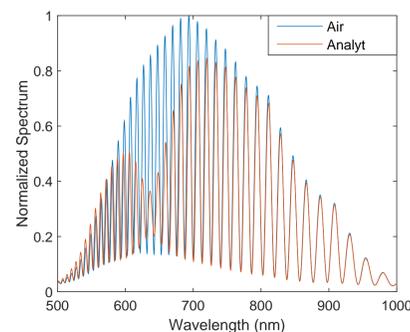

Figure 4: *Two channeled spectra with visibility decrease for SPR. Concentration of ethanol in water is 10 wt%.*
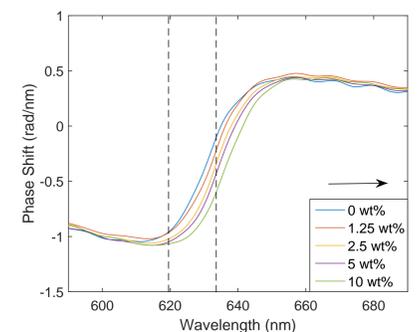
Figure 5: *Measured spectral phase shifts for analytes with different weight concentration of ethanol in water. Wavelengths used for sensing are marked by dashed lines.*

As in the theoretical part of this paper, two wavelengths are specified (see Fig. 5). At the first wavelength (λ_1=633.7 nm) the differences between the values of the phase shifts are the most significant. At the second wavelength (λ_2=619.96 nm) the trend is linear (see Fig. 6).
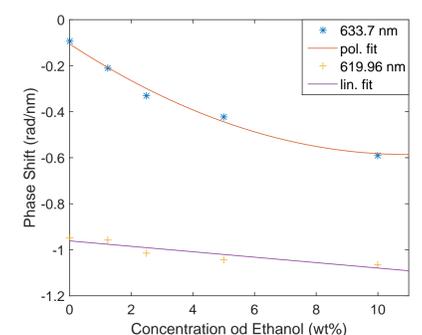

Figure 6: *Phase shift dependence on weight concentration of ethanol in water measured at two different wavelengths.*
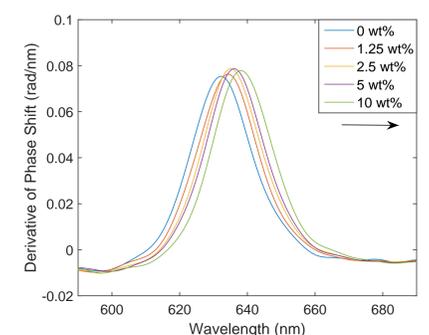
Figure 7: *Derivative of spectral phase shift as a function of wavelength for various weight concentrations of ethanol in water.*

In Fig. 7, spectral derivatives of the phase shifts are shown. At certain wavelengths, there are some maxima. They correspond to the resonance wavelengths – the wavelengths, where reflectivity of p-polarized wave decreases due to the SPR phenomenon. In Figs. 8 and 9 the dependencies of these resonance wavelengths on concentration of ethanol in water are shown.
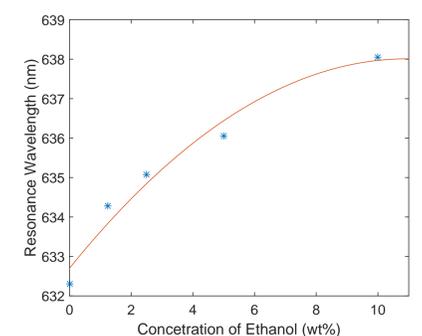

Figure 8: *Resonance wavelength as a function of the weight concentration of ethanol in water – theoretical results.*
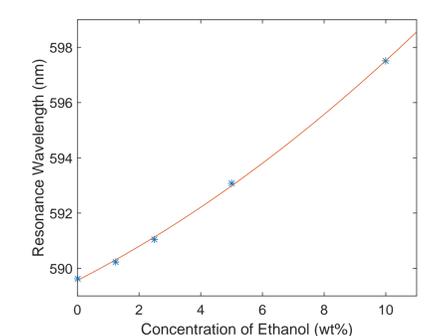
Figure 9: *Resonance wavelength as a function of the weight concentration of ethanol in water – experimental results.*

4. Conclusions

- A spectral interferometric technique to detect the phase shift induced by SPR in the Kretschmann configuration was used in sensing small refractive index changes in a liquid analyte.
- Significant mismatch between theoretical and experimental results was revealed - it is due to insufficient dispersion characteristics of the metallic layers in the SPR structure. It is necessary to find better way to describe the real layers with all their imperfections. Results are still important from the point of view of employing new sensors with high sensitivity.

References

[1] P. Hlubina *et al*, *Opt. Commun.* **354**, 240–245 (2015).

[2] P. Hlubina, D. Ciprian, *Plasmonics* **12**, 1071–1078 (2017).