Investigation on Low-loss Materials for Plasmonic Applications

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The high conductivity and the low optical losses make indium tin oxide interesting for plasmonic applications. Plasmonic effects can be identified in the dielectric function of the material. Therefore optical characterization by the Spectroscopic Ellipsometry and the influence of rapid thermal annealing (RTA) on the dielectric function of indium tin oxide are presented.

1 Introduction

Surface plasmon polaritions (SPP) couple light to an area smaller than the diffraction limit and can improve sensors due to their high light matter interactions.

Conventional plasmonic materials as gold and silver show high absorption losses, given by the imaginary part of the dielectric function. As a result the implementation of devices like a waveguide is rather difficult.

Hence, a large number of materials with a metallic character ($\varepsilon_1<0$) and lower losses have been investigated in the last years. Promising materials are ZrN, TiN, GaN and the group of the transparent conducting oxides (TCO's) [1]. Belonging to the latter the optical properties of indium tin oxide (ITO) are investigated in this paper.

2 Methods

An indium tin oxide thin film is deposited on a silicon substrate using the Ion Beam Sputter Deposition.

In the spectral range from 300 nm to 1700 nm the optical constants of the layer with a thickness of approximately 100 nm are determined by Spectroscopic Ellipsometry. For the fitting procedure the Drude-Lorentz model is used, which includes the interband transitions (Lorentz term) and the intraband transitions (Drude term) of the carriers [2]. This model describes the physical interaction with light rather well and results in reliable fits of the measured quantities Ψ and Δ (Fig.1).

It is given by:

$$\varepsilon = \varepsilon_{Drude} + \varepsilon_{Lorentz} = 1 - \frac{\omega_p}{\omega - i\gamma_D\,\omega} + \frac{A}{(\omega_0^2 - \omega^2) - i\gamma_L\,\omega}$$

The values of the dielectric function in the spectral range λ > 1700 nm are determined by an extrapolation using the Drude-Lorentz parameters.

3 Experimental Results

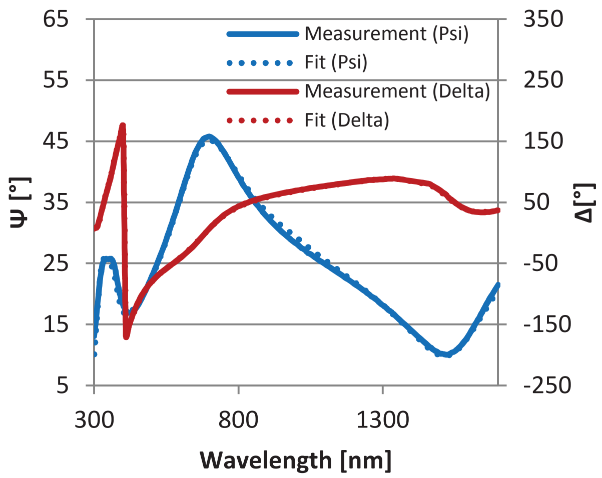

Fig. 1: *Model-Fit of the ITO thin film*

The complex dielectric function of the indium tin oxide thin film is shown in Fig. 2. A Lorentz oscillator is located at $\lambda \approx 260$ nm and the plasma frequency of the Drude model is $\omega_P \approx 11980$ cm^{-1}. Compared to gold and silver the indium tin oxide thin film shows smaller absorption values (ε_2) in the near infrared range.

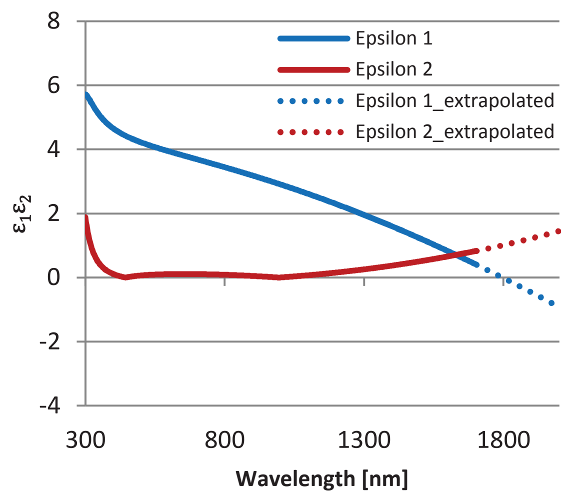

Fig. 2: *The dielectric function of ITO*

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The real part of the dielectric function becomes negative in the spectral range λ > 1800 nm. There plasmonic effects can be expected for a conventional indium tin oxide sample.

The optical properties of the indium tin oxide thin film can be modified by rapid thermal annealing. Due to the short temporal heating and cooling the oxygen atoms leave the indium tin oxide bond. The free places are filled by indium atoms leading to a higher conductivity [3].

This shifts the Drude absorption to shorter wavelengths (Fig. 3) and the real part of the dielectric function becomes negative at wavelengths λ > 1250 nm. There the absorption values are smaller than the absorption values of the untreated sample.

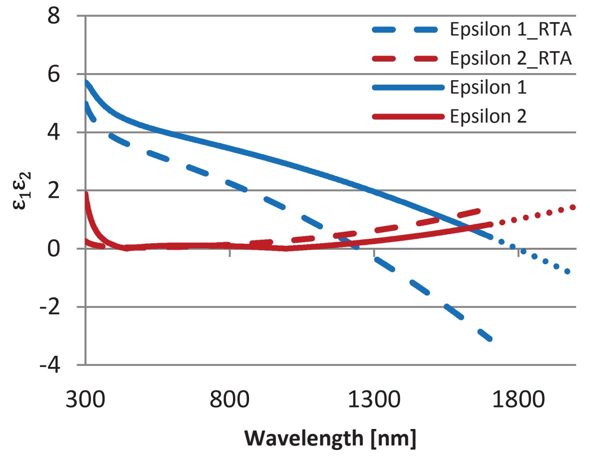

***Fig. 3:** The RTA effect on the dielectric function of ITO*

The result is a shift of the calculated surface plasmon resonance from λ ≈ 2050 nm to λ ≈ 1450 nm (Fig. 4).

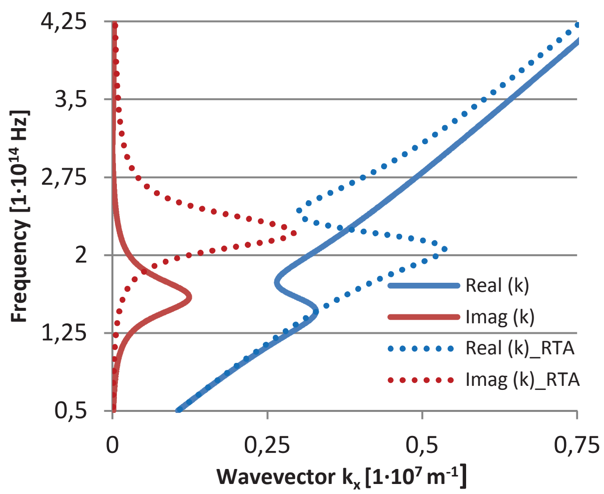

***Fig. 4:** Calculated SPP dispersion relation*

The surface plasmon resonance is calculated by the followed dispersion relation assuming an interface of air and an indium tin oxide thin layer.

$$k_x = \frac{\omega}{c}\sqrt{\frac{\varepsilon_1\varepsilon_2}{\varepsilon_1+\varepsilon_2}}$$

The magnitude of the resonances reaches values near the magnitude calculated from a gold layer. So the huge field enhancement makes indium tin oxide interesting for applications using the local surface plasmon resonance (LSPR).

4 Summary and Outlook

The optical characterization of indium tin oxide thin layers was successful. Compared to gold and silver indium tin oxide shows much lower absorption losses in the near infrared range. Additionally the use of rapid thermal annealing shifts the surface plasmon resonance to wavelengths near the telecommunication wavelength.

The next step is an experimental setup to excite a surface plasmon on an indium tin oxide thin layer. Furthermore GaN, ZrN and TiN are investigated concerning their plasmonic properties.

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References

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