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Silicon-based Surface Plasmon Resonance Biosensor

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Surface Plasmon Resonance (SPR) is now considered as a leading instrumentation for direct, label-free detection of recognition and binding events between a reactant from a solution (antigens, DNAs, etc.) and their analyte partner (antibodies, capture probe DNA, proteins etc.) immobilized to the surface/liquid interface. Conventional SP systems are based on a glass technology, in which p-polarized light is directed through a glass prism and reflected from a gold film deposited on its surface. SPR effect causes an appearance of a dip in angular (wavelength) dependence of the reflected light intensity, whose position is extremely sensitive to the refractive index or thickness of a thin biolayer on the gold. This remarkable property was employed for the development of SPR-based biosensors[1,2], which make possible a real-time characterization of biological interactions on the gold surface (fo review, see, e.g. Ref. 3).

The tendency of modern biosensing is the development of miniaturized, low-cost, integrated multi-sensor systems, including microchannels and micropumps. However, the implementation of such systems seems to be quite problematic in the frame of conventional glass-based SPR technology. We believe that the goal could be achieved if one adapts SPR technique to a silicon-based technology. In this case, well-developed silicon microfabrication methods could be applied in SPR configuration to miniaturize SPR-based biosensors and develop micro arrays.

We have examined theoretically conditions of Surface Plasmon excitation on a silicon platform and sensing response in configurations with spectral and angular interrogations. The analysis was based on a solution of Fresnel's equations for a light reflection from a multi-layered system. The case of a gold film sandwiched between silicon (silicon platform) and a tested dielectric medium was considered in detail and compared with the case of a gold film between glass (glass platform) and the tested medium.

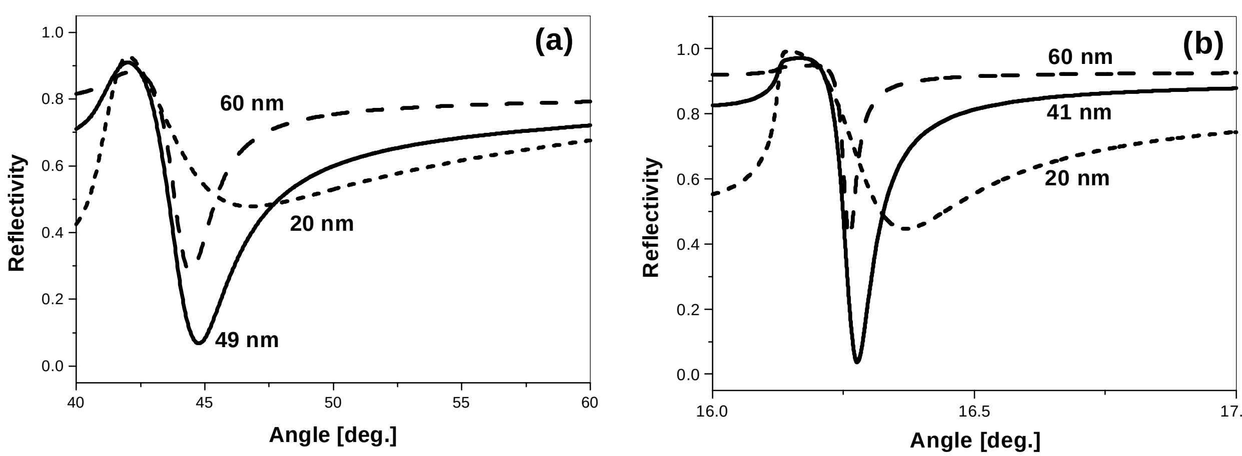


Fig. 1 Calculated reflectance R as a function of the incidence angle θ for various gold film thickness: (a) Glass platform, pumping light wavelength 600 nm; (b) Silicon platform, wavelength 1200 nm

It has been concluded from the theoretical analysis that the SPR effect on silicon is possible if infrared light with the wavelength above 1150-1200 nm is used for pumping and the gold thickness is properly selected. Fig. 1 shows typical angular dependencies of reflected intensities for the glass and silicon platforms. One can see that there was an optimal film thickness, which provided the most profound and sharp SPR dip. This optimal thickness was rathe similar in the cases of glass and silicon and was usually around 40-50 nm. However, the resonant angle for silicon (with respect to the normal to silicon/gold interface) was small (16.3° deg) in comparison with the case of glass (44° deg). In addition, the dip in the angular reflectance dependence was much narrower for the silicon platform. The width of SPR peak for silicon was less than 0.1° deg. FWHM in optimal conditions, while this parameter for glass was about 3-5° deg. It is necessary to note that similar reflectance dip occurred when the pumping light wavelength was varied under the fixed incidence angle. However, the width of the spectral dependence dip was comparable in the cases of the glass and silicon platforms.

It was established that the sensitivities of biosensors on the basis of glass and silicon platforms strongly depended on the way of interrogation. As follows from Fig. 2, the silicon-based biosensor demonstrated weaker sensing response to refractive index changes of the tested medium when the incidence angle was considered as the interrogation parameter (a). However, the situation was opposite in schemes with the spectral interrogation. In thi case, the silicon platform provided a considerable gain in the sensitivity, suggesting that spectral measurements are preferable for Si-based SP biosensors.

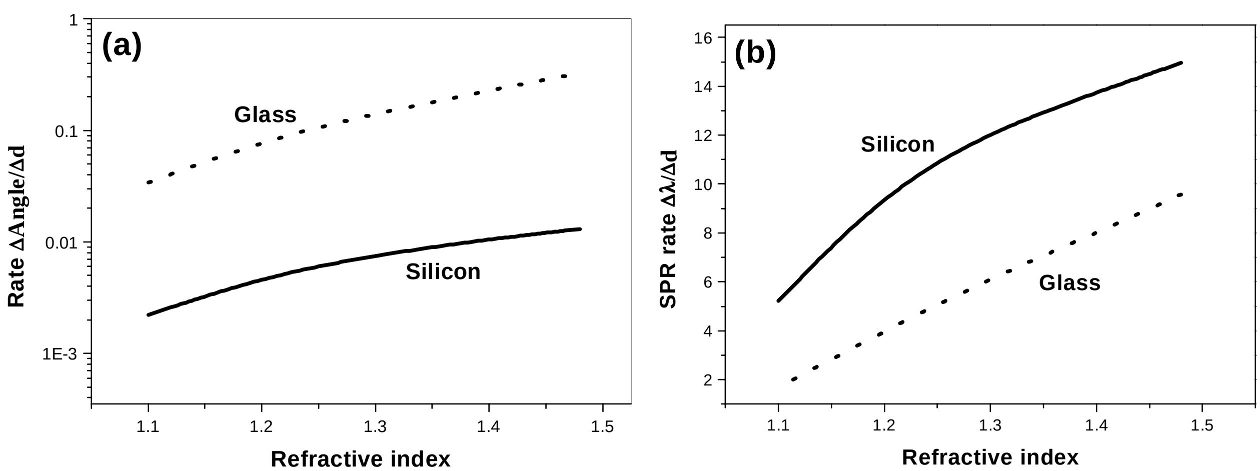
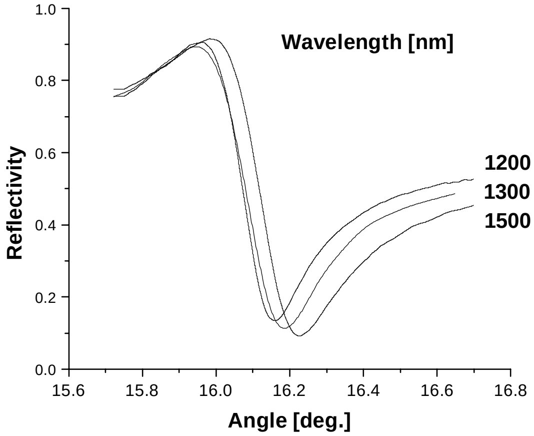


Fig. 2 Calculated sensitivities of SPR sensors on the basis of glass and silicon platforms as a function of the refractive index of the tested medium: (a) – angular interrogation (Δ(angle)/(Δd); (b) – spectral interrogation ($\Delta\lambda$)/(Δd). The refractive index change corresponds to a change of thickness (Δd) of a dielectric film on gold (initially, the gold film is in contact with air).

To verify the concept, we carried out an experiment with SPR production on a silicon platform. The IR radiation was directed through a Si wafer (FZ, 10-30 kOhm·cm) and reflected from a 50-nm gold film deposited on the backward wafer surface. To introduce the radiation to the wafer, the radiation was passed through a cylindrical glass prism, which was in immersion contact with the wafer. The reflected light intensity was analyzed by a photodiode. In the experiments, the light wavelength and angle of beam incidence could be varied in the range of 400 – 1600 nm and 0 - 90° (with respect to the wafer's normal), respectively.

Figs. 3 and 4 demonstrate a feasibility of the reproduction of the SPR effect on a silicon platform. The SPR dip can be clearly seen in schemes of both angular and spectral interrogation. It is interesting to note that the angular reflectivity curves were almost the same for quite different wavelengths of the pumping light. In contrast, the spectral reflectivity curves were very sensitive to the angle of incidence, suggesting that a precise angula adjustment is required for the spectral interrogation measurements.



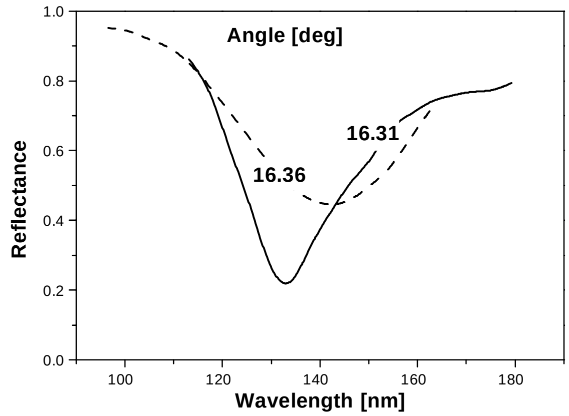


Fig. 3 Silicon platform: experimental reflectance R as a function of the angle of light incidence θ on the gold fil for different wavelengths.

Fig. 4 Silicon platform: experimental reflectance R as a function of the wavelength for various incidence angles θ.

In summary, we showed a possibility of SPR-based biosensor implementation on a silicon platform and examined sensing response in configurations of angular and spectral interrogation. The proposed biosensor could be miniaturized using silicon-based microfabrication methods.

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