Spectral darkness of multilayer semiconductor structures for biomedical sensor applications

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***Abstract* - Here the concept of point of darkness based on polarized light phase difference and perfect absorption of light is demonstrated by simulations using low refractive index semiconductor and dielectric, and high refractive index non-oxidizing metal multilayer thin film structures. The phase-sensitive and zero-light reflection can be designed not only for single wavelength and single incident angles, but also for broad spectral regions and for variety of incident angles. These simulations opens possibilities for further research on a new sensor development with particular spectral and phase-sensitivity.**

Keywords - point of darkness, semiconductors, phase-difference, phase-singularity, absorption of light, biomedical sensors

I. INTORDUCTION

The concept of point of darkness has received much attention for biosensing based on phase-sensitive detection and perfect absorption of light [1]. It is known that the absence of reflection can be achieved at a certain value of the incident angle (the Brewster angle) for specific wavelengths and polarization states. This principle works in the case of ideal optical systems, the light reflection from a single interface, prism-coupled surface plasmon resonance, parity-time metamaterial and coherent absorption. However, in case of such systems prototyping, the complete suppression of reflection is not possible due to sample fabrication errors (disorder, inhomogeneity, etc) and due to complex nano-patterning processes, which are required to realize metamaterials with topological darkness. Different subwavelength nanostructures have been proposed for the realization of topological darkness. Recently, it was reported on dispersion topological darkness at multiple wavelengths and polarization states using a three-layered structure where the top layer was nano-patterned [2]. Also simpler systems were reported, where the point of darkness is achieved by the multistack made of of silver (20 nm)/methyl methacrylate (522 nm)/germanium (10 nm)/silver (80 nm) [3].

These systems have some drawbacks. First, the technological difficulties to realize pattered thin film. Second, the choice of the materials: polymer materials, which often are not resistant at UV and humidity, and metals which in normal ambient are oxidizing, thus, changing the optical properties of the sensing device. Currently known systems, typically offer darkness at single wavelength, particular state of polarization and at single incident angle (Fig. 1 and Fig 3). Thus, it makes it difficult to realize such system as commercially available devices.

II. RESULTS

Here, we propose an innovative approach to realize perfect absorption and phase singularities using a simple metal-dielectric and metal-semiconductor-dielectric multilayer thin-film stacks, where semiconductors are low refractive index materials (n ≈ 2 @ 600 nm, e.g., YOH), dielectrics are inorganic materials (e.g., ZnO_x, SiO_x), and metals are not oxidizing (e.g., Au). Moreover, these materials can be easily fabricated by common vacuum thin film technologies used in semiconductor industries. In addition, we have designed the systems with multiple points of darkness (Fig. 3). In the simulations we use the complex dielectric dispersion curves obtained from spectroscopic ellipsometry investigations for ZnO_x [4] and semiconductor materials YOH developed in Thin Film Laboratory of our institute. The dispersion curves for SiO_X, Ag, Au and other metals are selected from the CompleteEASE optical constant library. The simulations are performed using CompleteEASE software by simulating (1) the ration of reflection coefficients r_p and r_s and (2) phase difference for *p*, *s* polarized light in the (250 - 1000) nm spectral range and (35 - 85)° incident angle of light.

III. ACKNOWLEDGMENTS

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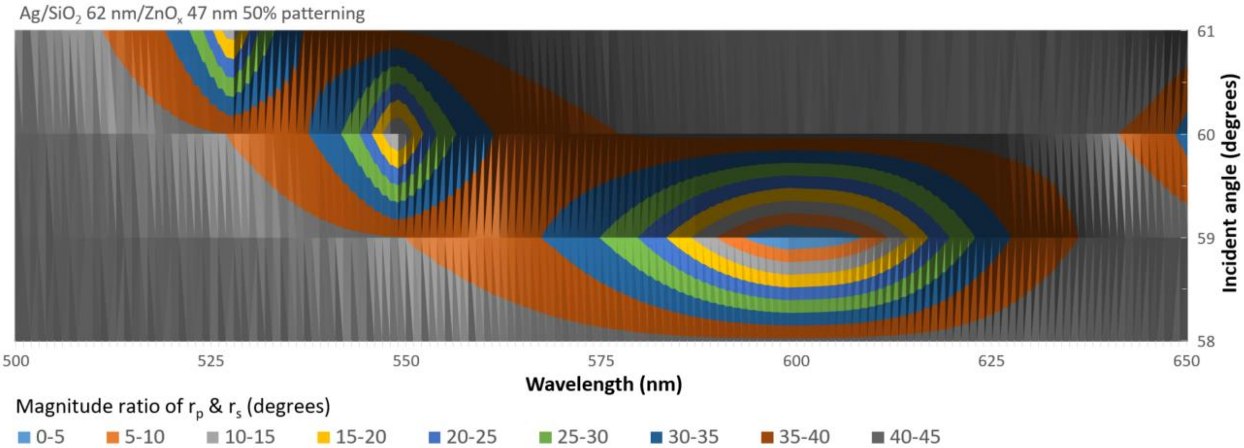

Figure 1. The 3D representation for the ratio of the reflection coefficients r_p and r_s for *p* and *s* policed light as a function of wavelength and incident angle of light. No reflection of light for patterned ZnO_x thin film at ~600 nm and at 59 degrees of incident angle.

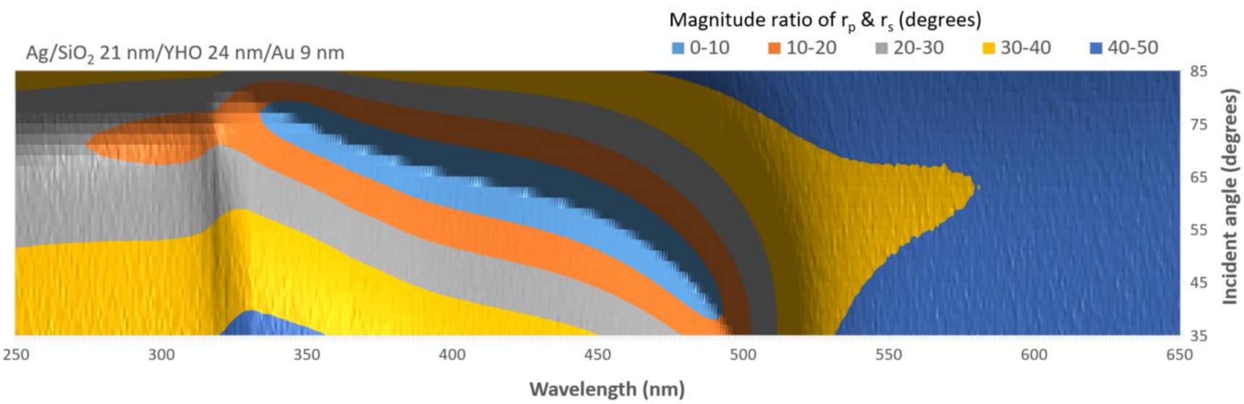

Figure 2. The 3D representation for the ratio of the reflection coefficients r_p and r_s for *p* and *s* policed light as a function of wavelength and incident angle of light. No reflection of light for multilayer structure of $Ag/SiO_2/YOH/Au$ at broad spectral range (~340-490 nm) for various incident angles (~36-75 degrees).

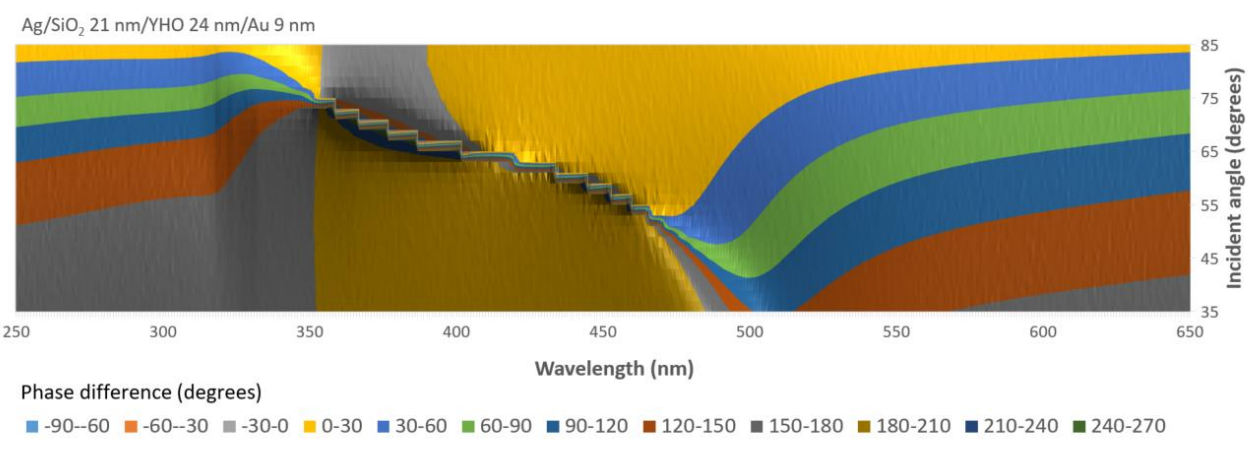

Figure 3. The 3D representation for the phase difference of *p* and *s* policed light as a function of wavelength and incident angle of light. Multiple phase-singularities (between -90° and +270°) for multilayer structure of $Ag/SiO_2/YOH/Au$ at broad spectral range (~350-465 nm) for various incident angles (~55-75 degrees).