Topological Darkness of Tamm Plasmons for High-Sensitivity Singular-Phase Optical Detection

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Abstract: Multilayered photonic-plasmonic structures can exhibit topologically protected zero reflection if they are designed to support Tamm plasmon modes. Sharp phase changes associated with the Tamm mode excitation dramatically improve sensitivity of optical detectors.

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Bio(chemical) sensors with optical transduction often rely on measuring the frequency shifts of the optical modes either due to the changes in the ambient refractive index or due to adsorption of molecules on the sensor surface. Environmental changes to be detected are often very small, and require interactions of light with the target material over long distances in order to accumulate large enough phase change that translates into the measurable optical mode frequency shift.

However, a phase of light is a cyclic variable, which is undefined at the point of complete destructive interference (a point of complete darkness), and varies rapidly in the vicinity of this point [1,2]. Light interference within a nanostructure that is accompanied by zero reflection and fast phase variations can be used to improve the sensitivity of bio(chemical) sensors with optical transduction [3,4].

Here, we demonstrate simple planar multilayered photonic-plasmonic structures that exhibit topologically protected zero reflection if they are designed to support Tamm plasmon modes (Fig. 1) [5,6]. The existence of Tamm states on the interface between the metal surface and the dielectric Bragg reflector is topologically protected provided the surface impedance of the Bragg mirror inside the photonic bandgap is tuned to match that on the metal surface [7]. The Bragg mirror surface impedance has been shown to be directly related to the bulk topological properties of the mirror through the geometrical (Zak) phases of its bulk photonic bands. By tailoring the Bragg stack optical properties, Tamm plasmon modes can be excited across a wide frequency range.

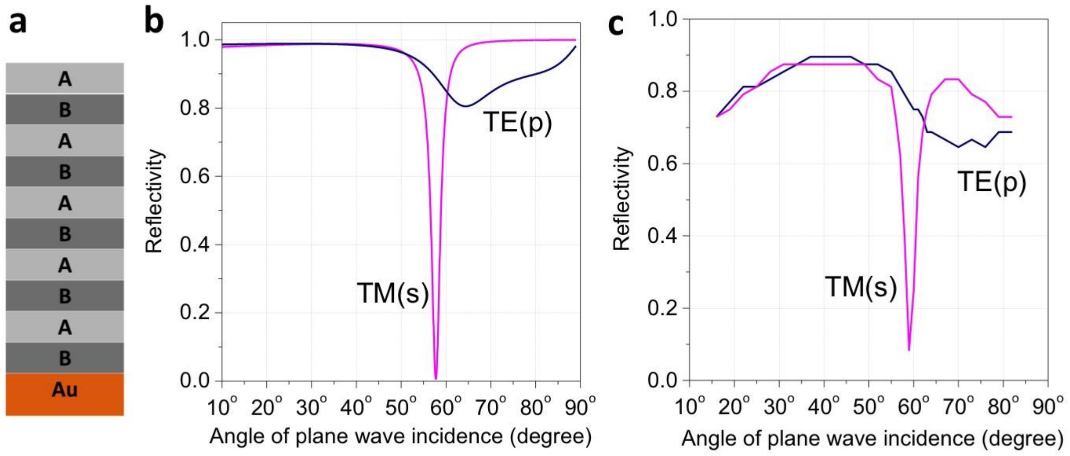

Figure 1. (a) A schematic of the Tamm structure composed of the dielectric Bragg mirror on top of a metal interface. Calculated (b) and experimentally measured (c) Tamm plasmon resonances in the structure composed of a Bragg stack of ZnS and MgF_2 layers on an Ag substrate at the excitation frequency of 632.8 nm and at operating temperature of 286 K.

We show how the sharp phase changes at the Tamm plasmon resonant frequency can be exploited to dramatically increase the sensitivity of optical detection as compared to a conventional resonance shift tracking detection scheme. The sensitivity increase is illustrated in Fig. 2, which compares the two detection schemes, and demonstrates the advantages of the singular-phase detection approach.

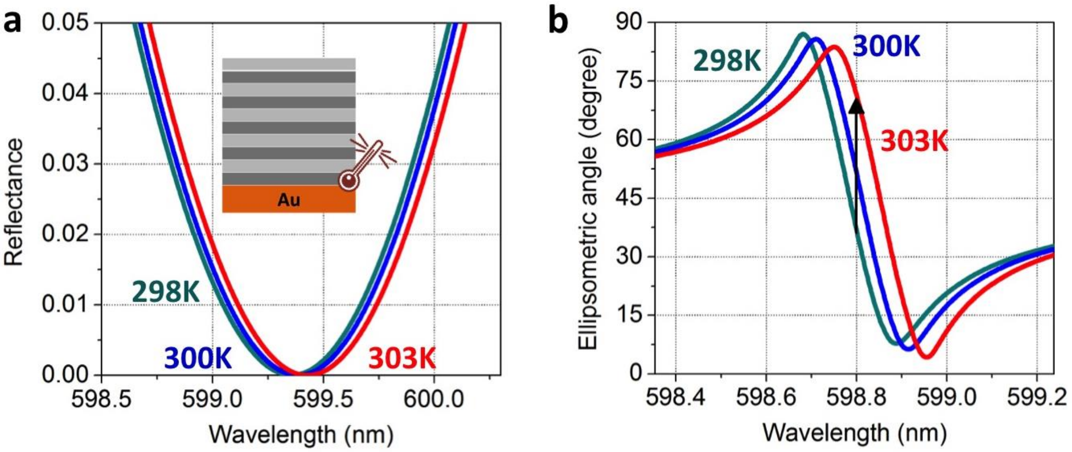

Figure 2. Calculated optical response of the Tamm plasmon sensor to the small changes in the temperature, measured as the resonant spectral feature shift (a) and the ellipsometric angle change (b). The structure is composed of SiC and SiO_2 layers on top of Au substrate, and light is incident normally to the surface. The significantly enhanced detection sensitivity in (b) is attributed to the local optical phase singularities in the sensor, which are accompanied by the rapid phase variations and vortex local optical powerflow.

It should be emphasized that the Tamm plasmon structure offers simplicity of the design, significant reduction of the fabrication procedure over previous singular-phase detection platforms, and superior tunability of the spectral position of the singular phase formation.

It also offers an opportunity to design sensors with passive radiative cooling functionality if polar dielectrics are used to construct the Bragg mirror. Such mirrors behave as hyperbolic metamaterials in the infrared spectral range, enabling broadband thermal emittance of the sensor surface [8–10]. The material transition into the hyperbolic regime is also underlined by the formation and re-configuring of local phase singularities in the optical interference field [8].

Acknowledgements

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