Singular-Phase Optical Sensing with Topologically-Protected Tamm Interfacial States in Planar Nanostructures

Citation: S. V. Boriskina, Y. Tsurimaki, and G. Chen, "Singular-Phase Optical Sensing with Topologically-Protected Tamm Interfacial States in Planar Nanostructures," in Advanced Photonics 2017 (IPR, NOMA, Sensors, Networks, SPPCom, PS), OSA Technical Digest (online) (Optical Society of America, 2017), paper SeW3E.5.

As Published: http://dx.doi.org/10.1364/sensors.2017.sew3e.5

Publisher: The Optical Society

Persistent URL: https://hdl.handle.net/1721.1/123877

Version: Author's final manuscript: final author's manuscript post peer review, without publisher's formatting or copy editing

Singular-Phase Optical Sensing with Topologically-Protected Tamm Interfacial States in Planar Nanostructures

Svetlana V. Boriskina*, Yoichiro Tsurimaki, and Gang Chen
Department of Mechanical Engineering, Massachusetts Institute of Technology, Cambridge, MA, 02139, USA
*sborisk@mit.edu

Abstract: We demonstrate an ultra-thin planar perfect absorber based on the excitation of a topologically-protected interfacial optical state and test its performance as a sensitive optical sensor in both the amplitude and phase detection schemes.
OCIS codes: (350.4238) Nanophotonics and photonic crystals; (350.1370) Berry's phase; (130.6010) Sensors; (240.6690) Surface waves; (260.6042) Singular optics; (240.6680) Surface plasmons.

The phase shift of the electromagnetic wave reflected from an interface exhibits singular behavior at frequencies where the reflectance vanishes. This phase discontinuity stems from the general principle of causality, represented in the Kramers-Kronig relations. Perfect photon absorbers exhibit sharp phase variations at frequencies of their absorption resonances, and this effect can be used to improve the sensitivity of bio(chemical) sensors with optical transduction. However, achieving perfect absorption condition often requires complex electromagnetic design and low-throughput fabrication techniques such as electron beam lithography.

To approach the extreme limit of shaping the frequency spectra of the ultra-thin *planar* absorbers, we developed theoretically and realized experimentally the conjugate-impedance matching approach to achieve perfect absorption with tunable narrow-band spectral lines. Typically, large mismatch between optical and electron length scales in thin films weakens light-matter interactions and reduces the absorptance. To alleviate this limitation, we designed and demonstrated spectrally-selective perfect absorbers based on topologically-protected interfacial optical states in planar multi-layered thin-film materials. These structures have tunable absorption lines, are easy to fabricate, and can incorporate ultra-thin and even 2D materials as absorbers.

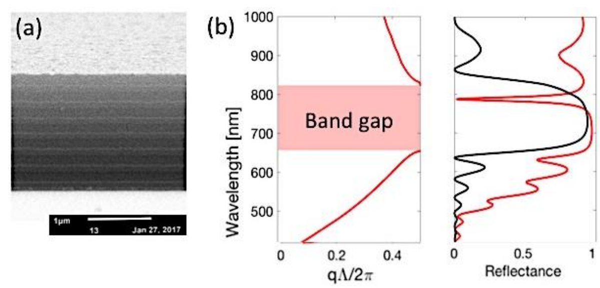

Fig. 1. Ultrathin narrowband perfect absorbers with topologically-protected interfacial Tamm states. (a) SEM image of the fabricated plnar absorber. (b) Narrow-band absorption line resulting from the conjugate impedance matching between a finite 1D PhC and a thin metal absorber.

One example of a planar structure that exhibits an interfacial (Tamm) state is a thin-film metal absorber integrated with a finite-length 1D photonic crystal (PhC) (Fig. 1a). The existence of Tamm optical states on the interface between the metal layer and the dielectric PhC is topologically protected provided the surface impedance of the bottom surface of the PhC facing the metal is tuned to match that on the metal surface. Perfect absorption can be achieved if the impedance of the absorber layer is conjugate-matched to the optical filter, which does not necessarily have to be a periodic PhC. The topological protection is achieved because the optical surface impedance is directly related to the bulk topological properties of the bulk material through the geometrical (Zak) phases of its photonic bands.

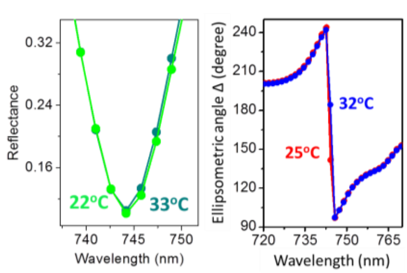

Fig. 2. Amplitude (left) vs singular-phase (right) temperature sensing scheme using Tamm state perfect absorber).

We demonstrate an optical sensing scheme based on the singular-phase detection with Tamm plasmon structures, which offers superior sensitivity to refractive index and temperature changes (Fig. 2).

Acknowledgement

This work was supported by the U.S. Department of Energy, Office of Basic Energy Sciences, Division of Materials Science and Engineering Award No. DE-FG02-02ER45977.