Electromagnetically induced transparency in square slotted dielectric metasurfaces supporting bound states in the continuum

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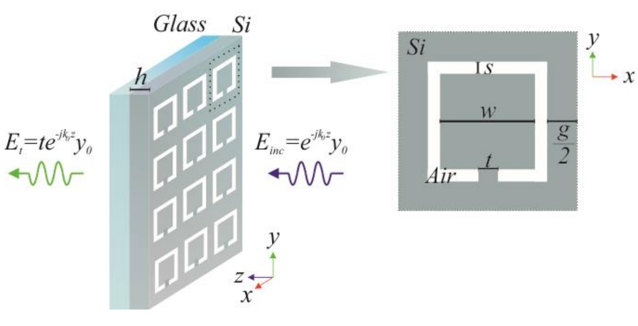
***Abstract*— In this work, a novel dielectric metasurface consisting of square slotted arrays etched in a silicon layer is proposed and theoretically demonstrated. The structure is designed to support electromagnetically induced transparency (EIT) based on quasi-bound states in the continuum (qBIC). Specifically, the metasurface consists of square slots with a silicon gap that breaks the symmetry of the structure. Thanks to the interaction of the sharp quasi-BIC resonances with a broadband background mode, an extremely high Q factor EIT response of $6{\cdot}10^6$ is demonstrated (considering the length scales feasible during fabrication and optical losses). Moreover, the resonator possesses a simple bulk geometry and subwavelength dimensions. The proposed metasurface, its high Q factors, and strong energy confinement may open new avenues of research on light-matter interactions in emerging applications in non-linear devices, lasing, biological sensors, optical communications, etc.**

Keywords—All-dielectric metasurfaces, bound states in the continuum, strongly resonant systems

I. INTRODUCTION

In recent years, the study of periodic structures has gained much attention. Specifically, metasurfaces (MS) are among the most researched structures, primarily due to their simple fabrication, compact transverse and extensive functionalities in manipulating and shaping the propagation of electromagnetic waves [1], [2]. They can be categorized into two major groups namely metallic and dielectric MS. The latter do not suffer from ohmic losses and allow both magnetic and electric resonant multipoles, making them a more appealing option for control the light, particularly in the visible and infrared spectrum. Based on this concept, many applications for dielectric MS have emerged in the last ten years [3], among which polarization control [4], photoluminescence [5], microwave waveguides [6], ultra-high Q response [7] or enhancement of nonlinear processes [8]. The traditional building blocks of MS have been cubes, disks, rods, or other geometrical shapes, usually in island-type configurations on a low-index dielectric substrate.

In this work, we propose a novel type of MS based on the building block of square slots in a silicon wafer (a mesh-type MS). We demonstrate that such slotted MS is capable of supporting electromagnetic induced transparency (EIT) based on quasi-bound states in the continuum (qBIC). The use of qBICs to achieve ultra-narrow EIT has only been recently reported [9]. The structural parameters of the MS are the slot width s, its inner side length w, the distance between adjacent slots g, and the silicon layer thickness, h, as depicted in Fig. 1. Hence, the pitch of the periodic square array is equal to $P=w+g+2s$. The slotted meta-atoms are interrupted by one narrow silicon gap, characterized by the gap length t. Moreover, the silicon gap establishes the continuity of the silicon layer, thus in principle allowing for the fabrication of the structure in both freestanding and substrate-supported structures.



(a) (b)

Fig. 1. (a) Schematic diagram of the proposed all-dielectric slot MS. The slots are etched in a thin silicon layer (white is air and grey is Si). (b) Detail of the unit cell and the MS geometrical parameters.

II. RESULTS AND DISCUSSION

In order to evaluate the optical response of the all-dielectric metasurface, the rigorous coupled-wave analysis (RCWA) is used. For this, a high-speed, open-source electromagnetic solver has been employed [10]. We consider a *y*-polarized, normally incident plane-wave, according to the definitions of Fig. 1. In a previous work, we observed that circular slots produced high Q resonances around λ = 1.55 µm, origingating from qBIC [11]. Here, we demonstrate that square slots produce broader resonances and possible control of the Fano resonance to produce EIT through parameter design. As a starting point, the structural parameters are selected to produce the broad resonance with the minimum transmission at λ = 1.55 µm (h = 278 nm, w = 496 nm, g_x = 240 nm, g_y = 120 nm, s = 35 nm and t = 0 nm). The gap breaks the symmetry, thus producing a leak on the BIC mode. The larger the gap the lower the quality factor, Q of the qBIC resonance.

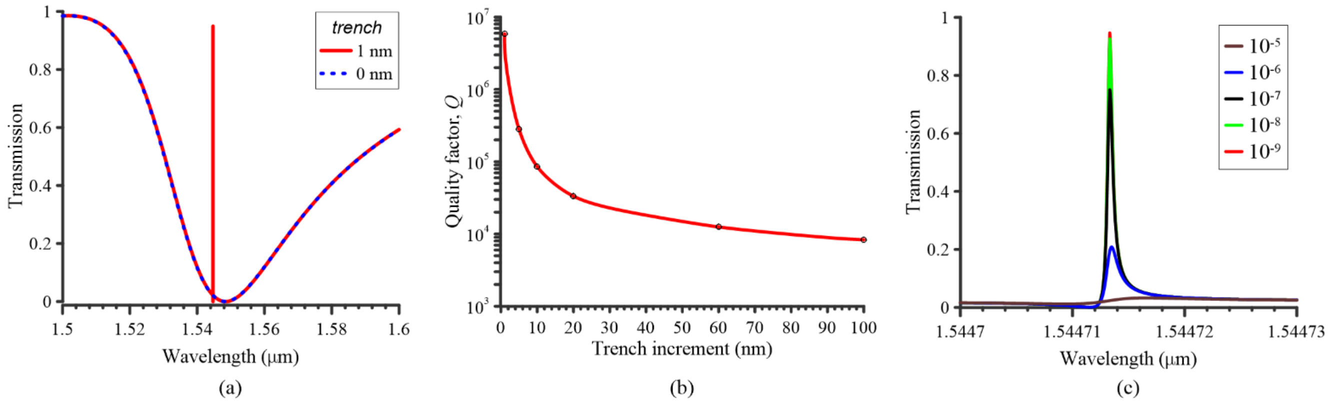


Fig. 2. (a) Transmittance of the investigated silicon metasurface for t = 0 nm and 1 nm. (b) Quality factor of the qBIC resonance in slot metasurface as a function of the gap size. (c) Transmission coefficient for different absorption cases when the gap size is t=1 nm. The quasi-BIC resonance ceases to manifest for $k > 10^{-5}$.

The symmetric ideal structure (lossless and infinite with t=0 nm) supports a symmetry-protected BIC, which does not manifest in the MS transmittance spectrum, as shown in Fig. 2(a). Upon breaking the MS symmetry the quality factor of the qBIC EIT resonance can be controlled by increasing the silicon gap length, as demonstrated in Fig. 2(b). The effect of losses is studied in Fig. 2(c) by adding an imaginary part (loss coefficient) to the silicon refractive index. It is important to note that for $k > 10^{-5}$, the quasi-BIC resonance ceases to manifest. This effect demonstrates the extreme sensitivity of quasi-BICs to losses and defects. This novel approach opens up new possibilities to obtain EIT in MS with ultra-high Q. Besides, its high Q factors and strong energy confinement can be exploited in several applications such as non-linear, lasing, or sensing devices.

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