Double electromagnetically induced transparency resonance in slotted metasurfaces supporting bound states in the continuum

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***Abstract*—This work proposes and theoretically demonstrates a double electromagnetic induced transparency resonance generated by a novel dielectric metasurface consisting of a periodic array of square slots. The resonances stem from symmetry-protected bound states in the continuum whose quality factor tends to infinity when the structure is symmetric. The quasi-bound states in the continuum supported by the asymmetric metasurface can be exploited to obtain double high quality factor resonances in transmission (electromagnetic induced transparency like effect) that can be modulated with the external refractive index for sensing.**

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

I. Introduction (*Heading 1*)

In recent years, the research on dielectric metasurfaces (MS) has grown exponentially. Several exciting effects manifest thanks to magnetic and electric resonant multipoles, which lead to numerous applications, e.g. control of light emission [1], polarization control [2], sensing [3], microwave waveguides [4], ultra-high quality factor resonant response [5], highly-selective filtering [6], or enhancement of non-linear processes [7] among others. Furthermore, it is also worth noting the electromagnetic induced transparency (EIT)-like effects on different MS structures [8]. In contrast to plasmonic MS that only obtain maximum Q-factors around 10 [9], [10], dielectric MS can have Q-factors orders of magnitudes higher thanks to the very low non-radiative losses. Such strongly resonant systems are often based on the so-called bound states in the continuum (BIC). Experimentally values of 18511 (array size of 27x27) [11] and 1000 (array size of 15x15) [12] have been obtained.

A novel type of MS made of squared slots etched on a silicon-on-glass substrate is proposed and theoretically demonstrated in this work. This structure can produce a double EIT resonance based on quasi-bound states in the continuum (qBIC). The structure has several parameters that can be tuned to obtain the resonances at the desired wavelength. In the investigated case, we define the parameters as the slot width s, inner side length w, distance between adjacent slots g, and silicon layer thickness, h (see Fig. 1). Thus, the pitch of the periodic square array equals $P = w+g+2s$. In order to obtain the qBIC, the symmetry is broken by narrow silicon joint, characterized by the gap joint t.

II. Results and Discussion

To evaluate the MS optical response, we have worked with RETICOLO software [13]. This software is based on rigorous coupled-wave analysis (RCWA). The wave polarization is along the y axis, and a normally incident plane wave is considered. A previous work studied a circular slot configuration obtaining high Q resonances around $\lambda = 1.55$ μm in reflection, originating from qBIC [14]. Here, the qBIC resonance ("dark mode") is designed to couple to a broad "bright mode" in order to have EIT. As a starting point, the structural parameters are selected to produce the minimum of the transmission (broad resonance) at $\lambda = 1.55$ μm ($h = 291$ nm, $w = 541$ nm, $g = 125$ nm, $s = 30$ nm and $t = 0$ nm). Then a small joint breaks the symmetry, producing a leak on the BIC mode, which allows for coupling with the incident planewave. As it happens with BICs, the larger the joint, the lower the quality factor, Q of the qBIC resonance.

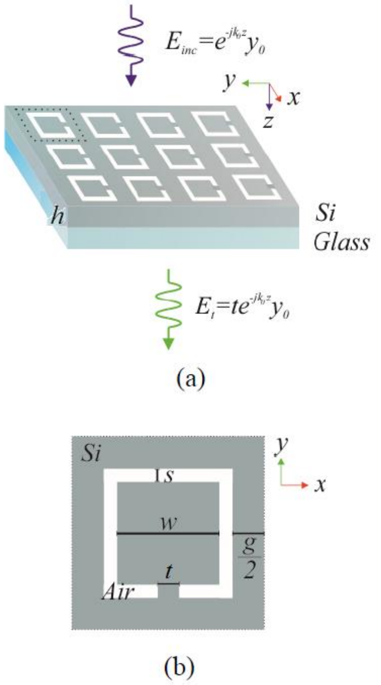

Fig. 1. (a) Depiction of the square slotted MS. Slots are etched in a Si layer forming grooves with a high aspect ratio. (b) Detail of the MS unit cell and the geometrical parameters.

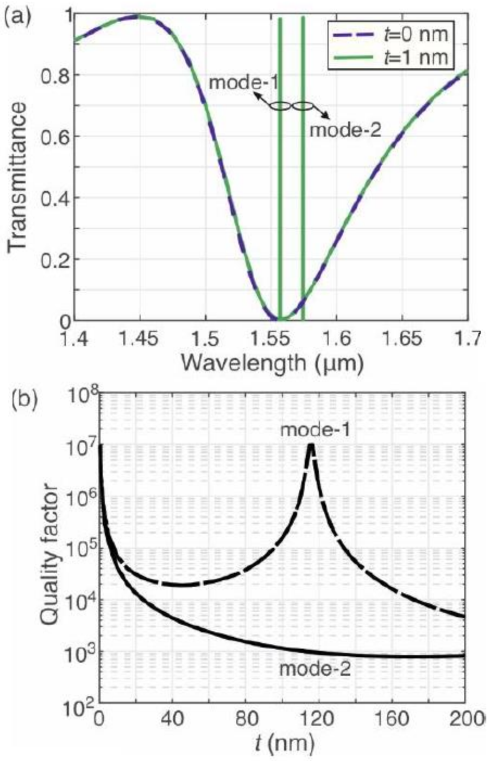

Fig. 2. (a) Transmittance of the silicon MS: (a) comparison between the symmetric (magenta) and asymmetric unit cell (green) (t = 1 nm). (b) The quality factor of the qBIC resonance in slot metasurface as a function of the joint size for the two observed modes.

As shown in Fig. 2(a) when the structure is symmetric, the two symmetry-protected BIC do not manifest (dashed line). If the symmetry is broken by the joint as in Fig. 1, a double high-quality factor qBIC EIT resonance is generated (continuous line). The effect of the joint size is studied in Fig. 2(b), both modes tend to infinity for $t = 0$. Also, an interesting effect can be observed for Mode 1 around 120 nm, which has to be further investigated. Thanks to this novel structure, ultra-high Q factor can be obtained in transmission, making it more appealing for emerging applications as non-linear MS, or sensing devices.

Acknowledgment

This work was supported by Comunidad de Madrid and FEDER Program (S2018/NMT-4326), the Ministerio de Economía y Competitividad of Spain (TEC2016-77242-C3-1-R and TEC2016-76021-C2-2-R), the FEDER/Ministerio de Ciencia, Innovación y Universidades and Agencia Estatal de Investigación (RTC2017-6321-1, PID2019-107270RB-C21 and PID2019-109072RB-C31).

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