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Analogue of High-Q Transparency Band and Sensitivity in All-Dielectric Metasurfaces Supporting Bound States in the Continuum

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Abstract: Bound states in the continuum (BICs), which are characterized by their high-quality factor, have become a focal point in modern optical research. This study investigates BICs within a periodic array of dielectric resonators, specifically composed of a silicon rectangular bar coupled with four silicon rectangular blocks. Through the analysis of mode coupling, we demonstrate that the interaction between the blocks significantly modulates the eigenmodes of the bar, causing a redshift in all modes and enabling the formation of electromagnetically induced transparency based on BICs (EIT-BIC). Unlike typical EIT mechanisms, this EIT-BIC arises from the coupling of “bright” and “dark” modes both from the rectangular bar, offering novel insights for nanophotonic and photonic device design. Further, our systematic exploration of BIC formation mechanisms and their sensing properties by breaking structural symmetries and changing environmental refractive indices has shed light on the underlying physics. This research not only consolidates a robust theoretical framework for understanding BIC behavior but also paves the way for high-quality factor resonator and sensor development, as well as the precise control of photonic states. The findings significantly deepen our understanding of these phenomena and hold substantial promise for future photonic applications.

Keywords: bound states in the continuum; Q-factor; EIT-BIC; metasurface; electromagnetically induced transparency

1. Introduction

The bound state in the continuum (BIC) as a nonradiative electromagnetic state has been the focus of attention of many researchers. This state exhibits strong confinement by achieving a high degree of confinement of photons and reducing their radiation loss to a level that approaching zero [1,2]. The formation of quasi-BICs usually originates from the mutual interference between multiple leakage modes [3]; leaky modes are modes that are not fully confined and gradually lose energy to the surrounding environment or radiation continuum. Due to this energy leakage, they have a finite lifetime, which results in a broader linewidth in the spectral response. In contrast, quasi-BICs are states that remain localized and do not couple to the radiation continuum. They maintain their energy over time without significant loss, leading to an extremely narrow linewidth in the spectral response. These leaky modes play a dominant role in controlling the optical properties of dielectric nanoparticles and metasurfaces, such as absorption, scattering, and emission. By embedding a nonradiative BIC into an electromagnetically induced transparency (EIT) window [4] or by varying the coupling strength between different resonance channels [5,6], quasi-BICs with very narrow linewidth can be achieved, enabling fast switching between leaky modes and quasi-BIC modes [7]. The associated BIC-related high-Q resonances are valuable for producing detailed spectra and enhancing nonlinear effects with specific materials [8]. They show great promise in various applications, such as BIC-based...
chirality \[9–11\], lasers \[12,13\], beam shifting \[14–17\], the reduction of radiation loss \[18\], nonlinear effects \[19–21\], modulation techniques \[22,23\], and sensing techniques \[24\].

In photonic systems, a symmetry-preserving BIC located at the center of the Brillouin zone (Γ-point) is associated with a symmetry mismatch between the resonance mode and the radiation channel \[25\]. In contrast, BICs on in-plane wave vectors deviating from the Γ-point are known as accidental or resonance-trapping BICs \[26,27\], which are usually excited by destructive interference between isolated resonances \[28,29\]. In the last decade, researchers have studied the transition from ideal BICs to leaky quasi-BICs by ingeniously breaking structural symmetry, designing the geometry and materials of the system, and changing the incidence angle \[30–32\]. Through oblique incidence or breaking the structural symmetry \[33\], BICs with zero linewidth collapse into quasi-BICs with finite linewidth and high Q-factors in the form of Fano resonance or EIT resonance \[34\]. The classical analogue of EIT can evolve from the Fano resonance if the frequency detuning of the two modes is zero \(q = 0\) \[35,36\].

Compared to metallic metasurfaces, dielectric metasurfaces can largely avoid intrinsic ohmic losses, resulting in a very high Q factor \[37,38\]. Similar to electronic energy band structures, the dispersion and spectral properties of dielectric metasurfaces \[39\] can be engineered to support BICs. In addition to geometric symmetry-based design, the patterns supported by dielectric metasurfaces form multiple isolated bands, providing an additional degree of freedom for the creation of non-Γ-point BICs \[40–42\]. By introducing external perturbations to the surface of the dielectric elements, quasi-BICs can leak into the Fano resonance and achieve narrowing of the far-field lines, providing a new method for controlling strongly localized electromagnetic energy. Achieving the ideal BIC requires coupling between different modes, which is always a feasible strategy. Various structural designs have been proposed \[43–48\] and validated experimentally or numerically. The EIT effect \[49\] is a special case of resonance arising from two-mode interaction. The EIT effect occurs when the frequencies of a strongly damped oscillator and a weakly damped oscillator are perfectly matched. This effect shows great potential in the development of novel devices such as slow-light \[50\] photonic devices \[51\], sensitive sensors \[52\], and electromagnetically induced modulators \[53\]. Recent studies have realized the EIT effect by transforming a BIC into a quasi-BIC state, revealing the intrinsic connection between BIC and EIT phenomena \[54–56\]. Notably, by utilizing the coupling effect between silicon rectangular rods and silicon rectangular blocks, a high-quality factor EIT resonant element surface has been experimentally demonstrated \[57\]. The EIT system has also demonstrated efficient visible third harmonic generation, as well as degenerate and non-degenerate four-wave mixing \[58\]. These experimental results demonstrate the potential of coupled dielectric science, and this relationship offers many applications and novel fundamental effects. The interdisciplinary approach addresses several new directions in quantum nanophotonics, including strong light–mass coupling, bound states in the continuum, topological photonics, metasurfaces, photon sources, and levitated optomechanics \[59\]. Given the interest in exploring fundamental physical principles and facilitating technological applications, a deeper understanding of the EIT-BIC generation mechanism has become a hot research topic in this field.

In this study, we discovered multiple “bright” and “dark” modes in a periodic nanoresonator array that combines silicon rectangular bars and silicon rectangular blocks in a single lattice. A comprehensive analysis shows that for the “bright” and “dark” modes appearing in a single silicon rectangular bar, the coupling effect between the silicon rectangular blocks and the bar affects the eigenmodes of the silicon rectangular bar, leading to a redshift and the formation of an EIT-BIC. Thus, although the four silicon rectangular blocks themselves do not generate eigenmodes, they significantly affect the eigenmodes of the rectangular structure, thus generating an EIT-BIC, and this EIT-BIC is formed by the coupling of the “bright” and “dark” modes of the rectangular bar. It is fundamentally different from the typical EIT mechanism, which involves coupling from the “bright” mode of one element and the “dark” mode of the other element of the metasurface. It provides more opportuni-
ties to study the EIT-BIC phenomenon when two resonators are coupled with each other. In addition, the radiative Q-factors of these quasi-BICs reach up to $10^7$ and tend toward infinity at discrete points. These phenomena show that they are inversely proportional to the square of the asymmetry of the structure or the deviation of the wave vector in the plane. This finding not only unambiguously reveals the close connection between the EIT effect and the quasi-BIC states in dielectric resonators but also opens up new avenues for exploring multiple BICs. This has significant potential for the construction of resonators and sensors with high-Q factors and the precise manipulation of photonic states.

2. Analysis and Discussion

To reveal the role of coupling in the EIT-BIC excitation of a dielectric element surface, we designed a resonator made of a rectangular bar and four rectangular blocks. This resonator structure is made of silicon with a refractive index of $3.7$ and uses SiO$_2$ with a refractive index of $1.48$ as the substrate. The working principle is illustrated in Figure 1a. To obtain the transparent window of the EIT centered on the dipole frequency, the geometrical parameters are optimized as follows in Figure 1b: the length and width of the rectangular bar are set as $L_2 = 92 \, \mu m$, $W_2 = 25 \, \mu m$, respectively; the length and width of the rectangular blocks are denoted as $W_{11} = W_{12} = W_{13} = W_{14} = 25 \, \mu m$, and $L_{11} = 13.75 \, \mu m$, respectively; the thickness of silicon is $H_1 = 12.1 \, \mu m$; and the thickness of the SiO$_2$ substrate is $H_2 = 0.6 \, \mu m$. Lattice constants are fixed as $P_x = 92 \, \mu m$ and $P_y = 96 \, \mu m$. With the help of CST Studio Suite, we systematically calculated the transmittance spectra, Q-factor, and near-field distributions by varying the incident angle ($\theta$), the width of the rectangular blocks, and the ambient refractive index. As shown in Figure 1c, the Q-factor of at-$\Gamma$ BIC-I exceeds $10^7$ and increases sharply near zero; at-$\Gamma$ BIC-2 is similar to at-$\Gamma$ BIC-1, with a value of $10^6$. As shown in Figure 1d, the presence of the BIC is well-verified by the band structure calculation, which agrees with the spectral response results in Figure 2c.

![Figure 1](image-url) (a) Overall schematic of the metasurface. The geometry consists of an all-dielectric silicon resonator and a silicon dioxide substrate. (b) Schematic of the unit cell consisting of two coupled resonators. The geometrical parameters of the structure are $W_{11} = W_{12} = W_{13} = W_{14} = 25 \, \mu m$, $L_2 = 92 \, \mu m$, $H_1 = 12.1 \, \mu m$, and $H_2 = 0.6 \, \mu m$, with $P_x = 92 \, \mu m$ and $P_y = 96 \, \mu m$. (c) Calculated radiative Q-factor of the symmetric metasurface, $a = P_x$, and (d) calculated band structure.
To study the spectral response of the metasurface, a plane wave polarized along the Y-direction is used as the incident wave propagating along the Z-direction. As shown in Figure 2a, when only a single rectangular bar in the lattice structure exists, we observed the existence of three eigenmodes of the rectangular bar. In the bright mode, a leaky mode is observed at 2.2 THz, while in the dark mode, two symmetrically protected BIC modes are observed at 2.4 THz and 2.6 THz, respectively. The two symmetrically protected BICs become quasi-BICs as the incidence angle increases when illuminated at normal incidence. These two BIC modes do not overlap with the leaky mode. In Figure 2b, when only four rectangular blocks are present, the plane wave achieves complete transmittance, with no obvious reflection or absorption phenomena and no eigenmodes generated. When the four rectangular blocks are combined with the rectangular bars, as shown in Figure 2c, causing a redshift in all modes, no new modes are introduced in the considered band. Since the filling rate of the silicon material in the periodic metasurface has a significant effect on the effective refractive index of the metasurface, in general, an increase in the filling rate will result in a redshift of the modes. Meanwhile, since the “dark” modes (the two quasi-BIC modes) shift faster than the “bright” modes (the leaky mode), this speed difference contributes to the coupling between the “bright” and “dark” modes, resulting in the formation of EIT-BICs. In the existing literature, the EIT phenomenon is typically generated by the coupling of the “bright” modes with the “dark” modes, which in most cases, involves the coupling of different structural elements. However, in our proposed coupled resonator consisting of a single rectangular bar and four rectangular blocks, the observed EIT phenomenon, although also originating from the coupling of “bright” and “dark” modes, is noteworthy in that both the “bright” and “dark” modes are generated by the silicon rectangular bar individually, whereas the presence of the four silicon rectangular blocks changes the effective refractive indices of the structure so that the “bright” modes are uniformly shifted to the low-frequency bands, while the “bright” and “dark” modes shift. This discovery opens up a new research path for in-depth investigation of the interaction between EIT and BIC.

As shown in the spectral response in Figure 2d, an ideal “bright” mode is observed under normal incidence conditions (at an incidence angle of 0°). Two quasi-BICs as “dark” modes with a very high Q-factor begin to appear with a slight increase in the incidence angle of 1.75°. A sharp transmittance band with an extremely narrow width appears in the “bright” mode. The formation of this remarkable transparency window at the resonant angle is seen as a manifestation of the electromagnetically induced transparency effect. At the same time, since this state is also a quasi-bound state, it can be referred to as an EIT-BIC. In addition, we observed that the center frequency of the EIT-BIC stays constant as that of the incidence from 1.75° to 4.2°, while the linewidth increases from 0.0023 THz to 0.0056 THz, indicating a decrease in the Q-factor. For the quasi-BIC on the right, the overall frequency blueshifts as the incidence angle increases, with the center frequency changing from 2.416 THz at 1.75° to 2.437 THz at 4.2° and the linewidth correspondingly increasing from 0.014 THz to 0.053 THz.

The broadening of the EIT-BIC linewidth implies that as the angle of incidence increases, the initial quasi-BIC may gradually evolve into a state with a lower degree of localization. The coupling between the mode and the radiation field strengthens during this process, leading to an increase in linewidth. The increase in linewidth is typically associated with an increase in radiation loss, which in optical systems, is inversely proportional to the quality factor Q. Therefore, the increase in linewidth reflects a decrease in the Q-factor of the system and a rise in radiation loss. In dielectric structures with a specific symmetry, smaller angles of incidence may not be sufficient to break this symmetry and thus maintain a high level of localization. However, as the angle of incidence increases, the original symmetry may break, resulting in a transition from the BIC to a quasi-BIC state with radiation leakage. Moreover, an increase in the incident angle may change the interaction between the wave and the medium structure, which in turn, affects the
resonance conditions. Such a change may result in the original BIC resonance conditions no longer applying, leading to a shift to the quasi-BIC state with a wider linewidth.

![Image](image-url)

**Figure 2.** (a) Spectral response of the single rectangular bar in one lattice of the metasurface. (b) Spectral response of the four rectangular blocks in one lattice of the metasurface, as $B_1$, $B_2$, $B_3$, and $B_4$. (c) Spectral response of the metasurface with both bar and blocks. (d) Spectral response of the metasurface as a function of incident angle.

Here, we calculated the distribution of the near electric field in the X–Y plane at half the thickness of the Si metasurface. As shown in Figure 3a, the local electric field is weaker due to the lack of electric field radiation. It is obvious from Figure 3b that the near electric field is enhanced by more than 10-fold when a small tilt angle $\theta = 2.8^\circ$ is introduced, compared to $\theta = 0^\circ$ in Figure 3a. As shown in Figure 3c, the field potential gradually decreases with the increase in the angle of incidence; similar results are observed in Figure 3d–f. A quasi-BIC is an approximate bound state with a very high Q-factor, but it is not precisely an ideal BIC. Whereas an ideal BIC is completely localized and does not radiate energy to the outside world, a quasi-BIC may exhibit weak radiation leakage. Quasi-BICs are typically formed by multiple leaky modes through destructive interference that significantly reduces mode radiative losses, allowing the energy of the modes to remain mostly inside the structure. These small losses may result in quasi-BICs not being infinitely long-lived, but in practice, they are still usually very long-lived and are considered a very useful form of bound state. Quasi-BICs are usually found in systems with symmetries or other specialized structures, similar to those of true BICs, but small asymmetries in the system can lead to the appearance of these states. Although quasi-BICs are not as desirable as true BICs, they still have many similar properties and thus have received much attention in optics and other areas of research.
Typically, resonators have an inherent symmetry that results in a limited interaction between the incident light and the structure. By breaking this symmetry, a new coupling mechanism can be introduced that allows the otherwise bound state to interact with the normal incident light. To achieve this goal, several methods can be employed. First, asymmetric structures can be designed by introducing asymmetry in the geometry or

![Figure 3](image-url)

**Figure 3.** (a–c) Near electric field distributions on the X–Y cross-section at half thickness of Si metasurface for different incident angles around BIC-I. Corresponding frequencies are at 2.16 THz, 2.13 THz, and 2.13 THz, respectively. (d–f) Near electric field distributions on the X–Y cross-section at half thickness of Si metasurface for different incident angles around BIC-II. Corresponding frequencies are at 2.16 THz, 2.42 THz, and 2.44 THz, respectively.

EIT-BIC is a special state that combines the electromagnetically induced transparency effect with bound states in the continuum. EIT is a quantum optical phenomenon that significantly reduces the absorption of light by the medium when the coupling between the two energy levels matches the frequency of the external light field, thus making the light transparent at a specific frequency. In EIT-BIC, the existence of a highly localized mode in the continuum spectrum can be achieved by precisely designing the dielectric structure, which is similar to BIC, but its formation is achieved through the EIT mechanism, the interaction of two or more modes produces a transparent window. EIT-BIC has potential applications in realizing high-Q factor resonances, slow light effects, and highly sensitive sensors.

We know that a symmetrically protected BIC is an ideal BIC that does not radiate energy outward and has zero linewidth and thus cannot be detected in the electromagnetic spectrum. Therefore, to recognize symmetry-protected BICs, the metasurface supporting symmetry-protected BICs needs to be physically modified to couple with and partially leak into the extended state in the continuum. Oblique incidence of a light source and structural symmetry breaking are two common methods of physical modification. Through these physical modifications, the symmetry-protected BIC state is transformed into a quasi-BIC state with radiation leakage.

We observed the variation of quasi-BIC-I and quasi-BIC-II by varying the width of the four rectangular blocks simultaneously with oblique incidence. Figure 4a clearly demonstrates the co-occurrence of quasi-BIC-I and quasi-BIC-II at a fixed incidence angle $\theta = 2.8^\circ$. As the four rectangular blocks gradually increase in the transverse dimension by the same width, the line widths of quasi-BIC-I and quasi-BIC-II are gradually narrowed, and both show a tendency to redshift. This result indicates that quasi-BIC states with high-Q factors can be realized by appropriately adjusting the widths of the four rectangular blocks.

Typically, resonators have an inherent symmetry that results in a limited interaction between the incident light and the structure. By breaking this symmetry, a new coupling mechanism can be introduced that allows the otherwise bound state to interact with the normal incident light. To achieve this goal, several methods can be employed. First, asymmetric structures can be designed by introducing asymmetry in the geometry or
arrangement [60], such as utilizing irregular shapes, non-uniformly distributed elements, or asymmetric layouts. Next, introducing material properties that are anisotropic or non-linear can alter the propagation behavior of the light within the resonator [61], leading to a change in the coupling characteristics. Lastly, a multilayer structure in the resonator [62], in which each layer has distinct properties or symmetry, enables the realization of additional coupling mechanisms through interlayer interactions. These methods are applied individually or in combination, depending on the specific application requirements and resonator design. Coupling the bound state to the normal incident light by breaking the symmetry of the resonator structure opens up new possibilities for optical device design and performance enhancement.

We know that the transparent window of the EIT in the form of sharp radiation is triggered by two different mechanisms; one mechanism is coupling through tilting of the angle of incidence, while the other is coupling through symmetry breaking of the plane mirror. Next, we discussed in detail the results of realizing the quasi-BIC state by breaking the symmetry. Under normal incidence at $\theta = 0^\circ$, we kept the widths of $B_3$ and $B_4$, $W_{13} = W_{14} = 12.5 \, \mu m$, unchanged while gradually decreasing the width of $B_1$ and increasing the width of $B_2$ accordingly; the calculated transmittance spectra of the “bright” modes and the quasi-BICs were observed and analyzed.

![Figure 4](image-url)

**Figure 4.** (a) Transmittance spectra with the change in the width of the four rectangular blocks at the incidence angle $\theta = 2.8^\circ$. The selected widths are $W_{11} = W_{12} = W_{13} = W_{14} = 8.33 \, \mu m$, 16.67 $\mu m$, 25 $\mu m$, and 33.33 $\mu m$, respectively. (b) Transmittance spectra with a simultaneous decrease in the width of rectangular $B_1$ and a corresponding increase in the width of rectangular $B_2$ at the incident angle $\theta = 0^\circ$ with $W_{13} = W_{14} = 12.5 \, \mu m$. (c) Transmittance spectra of simultaneously decreasing the width of the rectangular $B_3$ and correspondingly increasing the width of the rectangular $B_2$ for the incident angle $\theta = 0^\circ$ with $W_{11} = W_{14} = 12.5 \, \mu m$.

As shown in Figure 4b, at normal incidence, the asymmetry of the structure gradually increases as $W_{11}$ decreases, while $W_{12}$ increases. The decrease in $W_{11}$ is matched by an increase in $W_{12}$. Two transparency windows (quasi-BICs) in the leaky mode with ultra-high Q-factors appear, and with careful observation, it can be seen that the spacing between them is also gradually increasing. As the width increases by 3.08 $\mu m$, the spacing between the two quasi-BICs increases by 0.0034 THz. Accordingly, it can be concluded that multiple quasi-BIC states with high-Q factors can be achieved by adjusting the widths of $B_1$ and $B_2$ to break the symmetry of the system. This finding is useful for understanding the underlying physical mechanism of the quasi-BIC phenomenon.

Additionally, we detailed the results of breaking the symmetry of the resonator by changing the dimensions of the rectangular blocks in the diagonal direction to achieve the quasi-BICs. Under normal incidence, we break the symmetry of the structure by keeping the widths of $B_1$ and $B_4$, with $W_{11} = W_{14} = 12.5 \, \mu m$ unchanged, while decreasing the width of $B_3$ and increasing the width of $B_2$. The results are shown in Figure 4c. As the asymmetry of the structure increases, the spacing between the two quasi-BICs in the leaky mode also increases. As the width increases by 4.16 $\mu m$, the spacing between the two quasi-BICs...
increases by 0.031 THz. Comparing Figure 4b with Figure 4c, we can see that changing the dimensions of the diagonally oriented rectangular blocks affects the quasi-BICs more significantly than changing the sizes of the neighboring rectangular blocks. The spacing between the two quasi-BICs changes faster. These results further confirm that breaking the symmetry of the resonator structure is an effective strategy to realize the coupling of the bound state to normal incident light.

In addition to changing the width of the rectangular blocks, we explored disrupting only the X-axis symmetry of the structure by adjusting the distance $\Delta y$ that $B_1$ and $B_2$ are moved down the rectangular bar at an incidence angle of $\theta = 3^\circ$. From the transmittance spectra, Figure 5 reveals a transition from a symmetry-protected BIC to an accidental BIC, accompanied by the appearance of two additional accidental BICs. Specifically, a symmetry-protected BIC was originally present at the position where $\Delta y = 0$. With increasing $\Delta y$, an EIT-BIC located in BIC-IV starts to form and subsequently fades away. At values of $\Delta y$ between 20 and 40 $\mu$m, the formation of a new accidental BIC is observed again. In addition, the presence of two accidental BICs is also detected in BIC-I. BICs are also formed in BIC-III, BIC-V, and BIC-IV. The generation of BICs during this symmetry-breaking process indirectly confirms the existence of a stable BIC at the original position in the symmetric structure. This transformation process not only demonstrates the dynamic evolution of BICs under the influence of structural asymmetry but also provides a new perspective for in-depth understanding of the behaviors of BICs in optical systems.

![Figure 5. Transmittance spectra of the rectangular $B_1$ and rectangular $B_2$ for an incidence angle of $\theta = 3^\circ$, with a change in the distance $\Delta y$ moved down along the rectangular bar and $\Delta y$ ranging from 0 to 70 $\mu$m.](image)

Studying the sensing characteristics of metasurface-based quasi-BICs is essential due to their high Q-factor and sensitivity to the environment. Tuning the ambient refractive index constitutes an effective way to influence the coupling between the bound state and the incident light. Changes in the ambient refractive index significantly affect the optical field distribution and propagation characteristics within the resonator, fundamentally altering how the bound state couples with the incident light. This method has broad potential for applications in optical device design and sensor technology.

The simulation results in Figure 6a show that both quasi-BICs are significantly red-shifted as the refractive index of the surrounding medium increases. Specifically, quasi-BIC-I shifted by 0.422 THz and quasi-BIC-II shifted by 0.574 THz as the ambient refractive index $n$ changed from 1 to 2. This indicates that they have sensitive sensing properties to the environment.
Figure 6. (a) Spectral response of quasi-BIC-I and quasi-BIC-II with the change in ambient refractive index at the incident angle of $\theta = 2.8^\circ$. The refractive indices are 1.0, 1.2, 1.4, 1.6, 1.8, and 2.0, respectively. (b) Center frequency of quasi-BIC-I at different ambient refractive indices. (c) Center frequencies of quasi-BIC-II under different ambient refractive indices. (d) FOM for quasi-BIC-I under different ambient refractive indices. (e) FOM for quasi-BIC-II under different ambient refractive indices.

In the field of optical refractive index sensing, sensing sensitivity (S) and figure-of-merit (FOM) constitute two core metrics for evaluating sensor performance. For refractive index sensors based on optical resonance modes, the sensing sensitivity is typically measured as $S = \Delta f/\Delta n$, FOM = $S$/FWHM, where FWHM is the full width at half maximum. The FOM has a non-negligible importance as an evaluation index of the comprehensive performance of optical refractive index sensors. The maximum sensitivity of quasi-BIC-I is $S = 457.6$ GHz/RIU, while quasi-BIC-II is $S = 607.5$ GHz/RIU. We found that the FOM of quasi-BIC-I under different environmental refractive indexes reaches up to 136.9844 RIU$^{-1}$ and the FOM of quasi-BIC-II can be up to 169.4734 RIU$^{-1}$, as shown in Figure 6d,e.

3. Conclusions

In summary, we systematically explored the formation mechanism and sensing properties of BICs in a metasurface consisting of a bar and blocks. Specifically, the coupling between the silicon rectangular blocks can effectively modulate the eigenmodes of the silicon rectangular bar, leading to a redshift in their frequency spectrum and the formation of EIT-BICs. Although the four silicon rectangular blocks alone do not exhibit significant eigenmodes, they significantly modulate the eigenmodes of the rectangular bar, contributing to the generation of the EIT-BIC. This EIT-BIC forms through the coupling of the “bright” and “dark” modes of the rectangular bar. This phenomenon is fundamentally different from the typical EIT mechanism. Meanwhile, in a medium structure with specific symmetry, the original symmetry may be broken with an increase in the incident angle, resulting in the transition from the original BIC to the quasi-BIC state with radiation leakage. Furthermore, it is found that high-Q BIC states can be realized by breaking the symmetry of the structure in different ways at specific incidence angles, and multiple quasi-BICs can occur simultaneously. In addition, we found that the sensitivities of quasi-BIC-I and quasi-BIC-II to the surrounding medium can reach up to $S = 457.6$ GHz/RIU and $S = 607.5$ GHz/RIU, respectively. The FOM of quasi-BIC-I and quasi-BIC-II at different ambient refractive indices can reach up to 136.9844 RIU$^{-1}$ and 169.4734 RIU$^{-1}$, respectively. These research results not only deepen our understanding of the physical nature of bound states in BICs and provide solid support for revealing the states of BICs in a two-resonator coupled system but also reveal the dependence between BICs and the surrounding medium, which provides new perspectives for the design of optical refractive index sensing devices. In addition, it has significant application prospects for the construction of high-Q factor resonators and sensors, as well as the precise manipulation of photonic states.
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