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Membrane Nanophotonic Platform for Enhanced Light-Matter Interaction of Transition Metal Dichalcogenide Monolayer

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Abstract: Strong coupling between the membrane metasurface and transition metal dichalcogenides (TMDC) monolayer via the quasi-BIC mode is demonstrated, presenting enhanced photoluminescence emission. The significance of membrane metasurface design for achieving highly confined quasi-BIC modes, distinct from conventional photonic guided modes, is clarified, offering new possibilities for 2D material-based nanophotonic and quantum devices.

In recent years, there has been significant interest in the strong light-matter coupling observed in monolayers of transition metal dichalcogenides (TMDCs) within the fields of optoelectronics and nanophotonics. A crucial aspect of improving the coupling between photonic structures and TMDC materials, facilitating interactions between photons and excitons, is optimizing the design of photonic structures specifically tailored for materials in the atomic-scale thickness. In the photonic structures, the dielectric metasurface supports the photonic bound state in the continuum (BIC), representing an optical mode confined within a structure without radiative losses. This unique characteristic results in exceptional light-matter interactions, making it an ideal choice for designing TMDC monolayer-based nanophotonic devices [1-3]. In the field of two-dimensional (2D) materials nanophotonics, there has been growing attention towards nanophotonic applications involving BIC modes.

To achieve BIC with a strong field enhancement and a quality factor at resonance approaching infinity in practicality, membrane structures, with their inherent two-dimensional nature, provide an ideal platform. The confinement and manipulation of light within the membrane structures introduce novel possibilities for enhancing light-matter coupling. Additionally, they enable control over optical properties when compared to conventional waveguide modes. Here, we demonstrate the strong coupling between the membrane metasurface and the TMDC monolayer via a quasi-BIC mode. Utilizing the membrane metasurface, the enhanced photoluminescence (PL) emission from the quasi-BIC mode is observed, presenting distinct differences from the emission behaviors of the conventional photonic waveguided mode.

Figure 1(a) illustrates the electric field enhancement distribution of the quasi-BIC mode in the membrane metasurface, demonstrating a significantly larger enhancement than that of the quasi-BIC mode in the substrate-based metasurface. This suggests the significance of the membrane metasurface design for achieving a highly confined quasi-BIC mode. Following the investigation of the membrane metasurface, the emission enhancement of the WSe_2 monolayer through the strong coupling of the TMDC monolayer to the membrane metasurface via the quasi-BIC mode, deviating from the conventional photonic guided mode, is demonstrated as shown in Figure 1(b). This study underscores the importance of membrane design for nanophotonic metasurfaces supporting BIC, opening a new window for 2D material-based nanophotonic and quantum devices.

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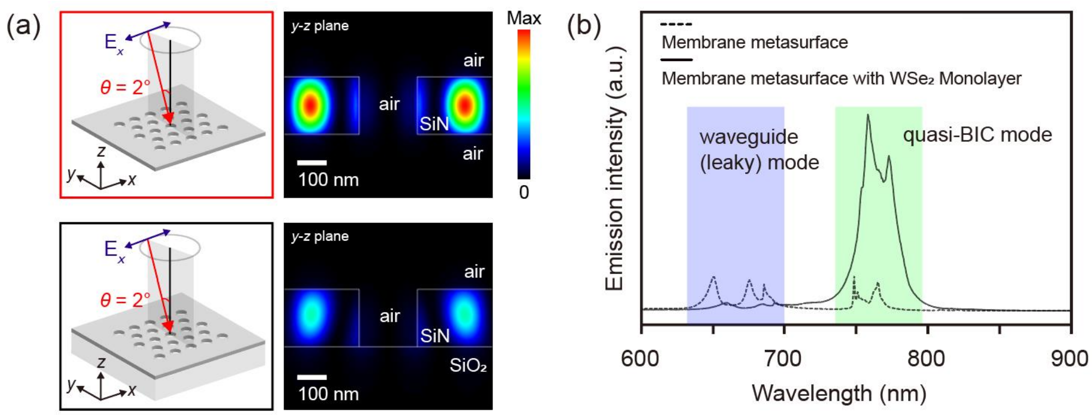

Figure 1. (a) Simulated electric energy density distribution at the quasi-BIC mode of the membrane metasurface (top) and the metasurface on the top of the SiO_2 substrate (bottom), with the incident angle and polarization indicated. (b) The PL emission spectra from the SiN membrane metasurface and the WSe_2 monolayer-membrane metasurface.

References

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