Bilayer Meta-optics in Visible Wavelengths for Moiré Flatbands

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Photonic moiré superlattices of misaligned bilayer structures have been shown to have rich phenomena, such as optical singularities[1], light localization[2], and flatbands[3]. To generate flatbands, the intra- and inter-layer coupling between meta-atoms needs to be comparable and fine-tuned.[4] Enhancing the interlayer coupling strength requires a close stacking of the two layers, with gaps varying from zero to dimensions close to the structure's period. Controlling the intralayer coupling strengths requires an efficient refractive index (RI) contrast. The conventional nanofabrication methods and material platforms for visible meta-optics face challenges in this case. Towards this end, we present a bilayer moiré superlattice fabricated through E-beam lithography and ALD backfilling of TiO_2. This TiO_2/air structure has an RI contrast close to 2.4 with controllable interlayer gaps.

Moiré flatbands, or nearly zero light group velocity, can be engineered in both 1D (grating type) or 2D (photonic-crystal type) structures. Figure 1(b) shows the numerically simulated (RCWA) reflectivity spectrum of one example flatband in the visible regime. The light is confined at AB sites of the bilayer grating structure, as shown in Figure 1(c). Figure 2 shows schematically the fabrication process of the presented device. The resist for each layer is patterned through E-beam lithography, followed by backfilling of TiO_2 through ALD until a flat top surface is achieved. The etching time controls the thickness of the inter-layer gap (TiO2 membrane). An Example of alignment between the two layers is shown by the SEM images in Figure 3.

The experimental demonstration of moiré flatbands, especially in visible wavelengths, will open new possibilities for exploring moiré photonics in nonlinear optics, wide angular band couplers, and AR/VR technologies. Furthermore, beyond two layers, the presented fabrication approach can realize multilayer meta-optics with high RI contrast in visible wavelengths.

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[2] H. Tang, X. Ni, F. Du, V. Srikrishna, and E. Mazur, On-chip light trapping in bilayer moiré photonic crystal slabs. Applied Physics Letters, 121(23) (2022).
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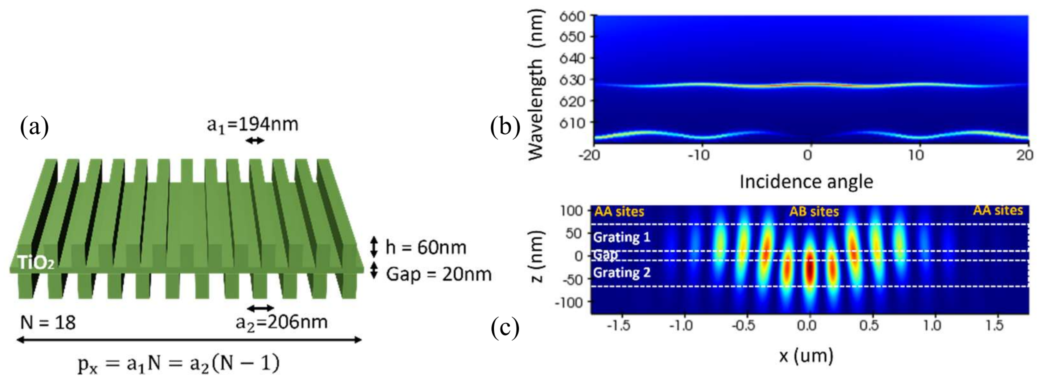

Figure 1: (a) Schematic diagram of a 1D moiré superlattice, in which TiO_2 (in green) is surrounded by air (except a SiO_2 substrate). The AB site is made as the center, where the top and bottom atoms are perfectly mismatched. (b) Reflectivity spectrum (simulated with RCWA). The targeted flatband is around 628 nm and has a bandwidth close to 1 nm. (c) The mode profile of the targeted flatband. Light is confined at AB sites.

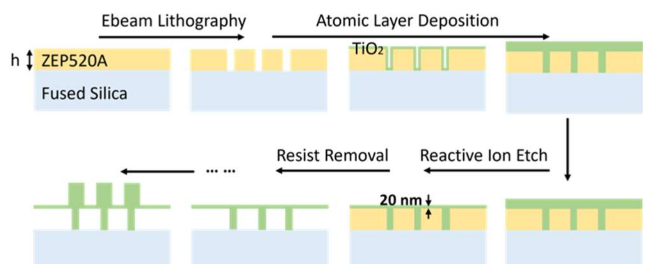

Figure 2: Fabrication steps for the presented bilayer moiré superlattice.

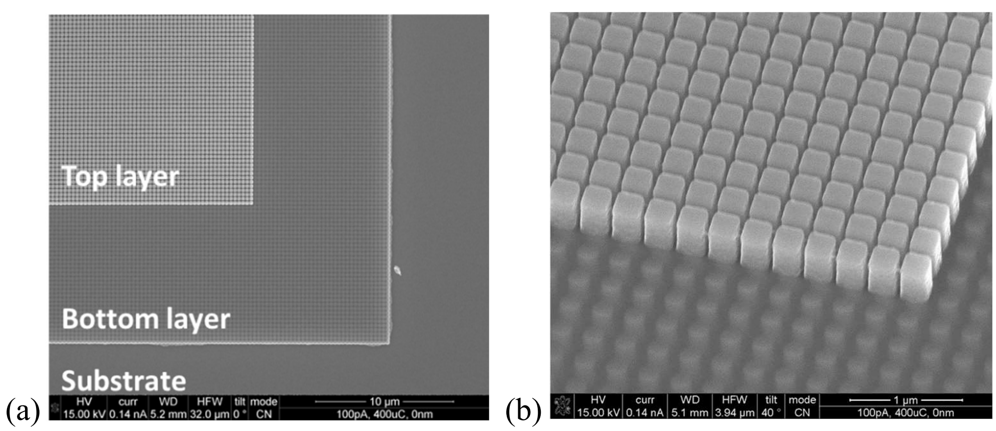

Figure 3: SEM images of an aligned bilayer TiO_2/air structure. (a) The top and bottom layers are separated by a ~20nm TiO_2 membrane, and the substrate is fused silica. (b) This example structure has a 300nm period for both layers. Each larger post in the top layer aligns correctly with the smaller one below.