Momentum-Resolved Electron Beam Spectroscopy for Plasmonic Bandgap Materials

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Next generation on-chip optical devices require light manipulation in time and space, that is, control of group velocity of light in subwavelength dimensions. A waveguide in plasmonic crystal (PlC) fulfills such requirements offering nanoscale light confinement in the dispersion-tunable plasmonic crystal matrix. Especially, PlCs with a triangular lattice (Tri-PlCs) are attractive due to full bandgap (FBG) formation, where no SPP propagation is allowed [1]. We have performed momentum-resolved cathodoluminescence (CL) and electron energy-loss spectroscopy (EELS) to characterize localized mode formed at defect structures introduced in Tri-PlCs.

Fig. 1a shows a schematic of momentum-resolved CL experiment on a line defect waveguide introduced in the Tri-PlC which was a silver dot array on a silver surface. The distance between the lattice points was 300 nm, and the diameter and the height of the dot were about 150 and 100 nm, respectively. Our angle selective light detection system is composed of a parabolic mirror and a scanning pinhole as depicted in Fig. 1b. The light emitted parallel to the *xz* plane was detected by successively changing the pinhole position in the *z* direction. Details of our experimental setup for momentum-resolved CL is described in Ref. 2. It should be noted that a more effective way to acquire energy-momentum maps was proposed in Ref. 3.

The main results of momentum-resolved CL on a line defect waveguide are shown in Figs. 2a and 2b [4]. Fig. 2a shows the dispersion patterns taken from the Tri-PlC matrix (left) and the line defect waveguide with a width of 520 nm (right). A dispersion curve of the plasmonic waveguide mode appears in the FBG (1.8 to 2.3 eV) of the Tri-PlC matrix, and the group velocity in the *x* direction is 7.5 times slower than the light speed in vacuum by assuming a linear dispersion in the range of 1.95 to 2.10 eV. We also obtained photon maps of the waveguide mode to visualize propagation behavior (Fig. 2b). To detect non-radiative modes, we connected the Tri-PlC waveguide to a one-dimensional grating (left end) which can convert plasmons to photons in the corresponding energy region. The decay of the waveguide mode is observed. The above momentum-resolved spectroscopy is also applicable to other important waveguide modes such as topological edge modes [5].

As shown in the above, momentum-resolved CL is a very powerful technique to explore periodic nanostructures like PlCs. However, CL can not directly detect nonradiative modes like the lowest bands including the important reciprocal lattice point K in the Tri-PlCs. So we conducted momentum-resolved EELS as an alternative method to directly identify the FBG of the Tri-PlC using a monochromated electron microscope with sub-μrad angle resolution and sub-100 meV energy resolution. As a result, the FBG opening was verified by detecting the band-edges of the M and K reciprocal lattice points. Moreover, a localized mode was found in a point defect and the energy level was located within the FBG.

References:

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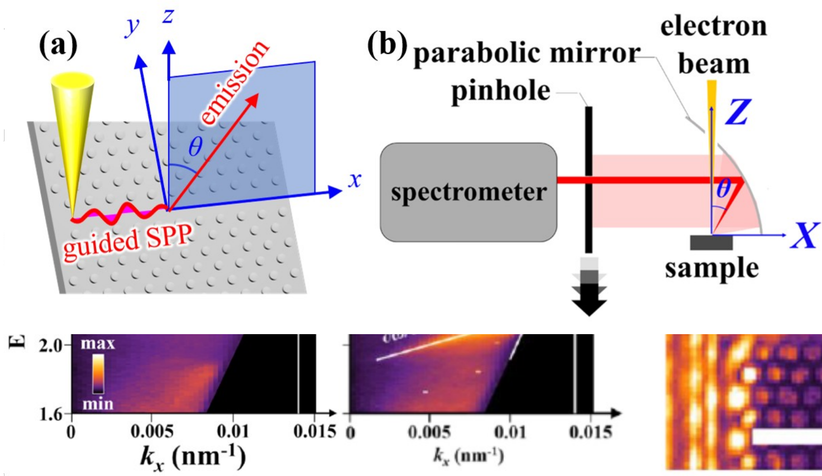

in the Tri-PlC waveguide. (b) Angle-
nicroscope.

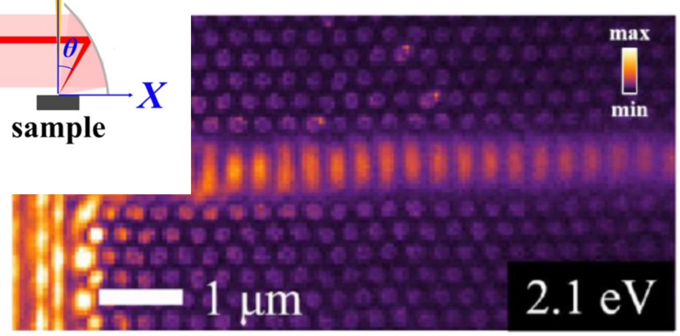

Figure 2. (a) Dispersion patterns taken from a Tri-PlC with no defect (left) and a 520 nm-width line defect waveguide (right). (b) Monochromatic photon map of a PlC waveguide with a line defect width of 1040 nm connected to the 1D grating taken at 2.1 eV.