Spatially nonreciprocal Bragg gratings based on surface plasmons

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Abstract—The concept of spatial non-reciprocity in surface plasmon based Bragg gratings is introduced. It is shown that balanced modulation of index and gain/loss with quarter pitch spatial shift cause a nearly perfect unidirectional coupling between contra-propagating modes in a long range surface plasmon polariton Bragg grating. Such a Bragg grating operates at the breaking threshold of parity-time symmetry. Parity-time (PT) symmetric optical materials are synthetic materials in which the refractive index of the structure is judiciously synthesized to form \( n(z) = n^*(z) \). This condition is necessary but insufficient for having PT symmetry structure. By altering the refractive index of the structure at a certain critical threshold, PT symmetry breaks down sharply. This breaking threshold is referred to as an exceptional point or spontaneous phase transition, where many fascinating optical phenomena can be observed. A Bragg grating with matched modulation of real (index) and imaginary (gain/loss) refractive index, where the perturbation of gain/loss versus the real index perturbation is quarter-period shifted spatially, is an example of a PT symmetric structure operating at the breaking threshold. The refractive index distribution of such a Bragg grating can be written as:

\[
n(z) = n_0 + \Delta n_0 \exp \left( \pm \frac{j 2\pi z}{\Lambda} \right)
\]  

(1)

where \( \Lambda \) is the period of the grating. Using coupled mode theory, coupling from the forward to the backward propagating mode is directly related to the Fourier components of the periodic refractive index. For a refractive index with single sideband spectrum, such as the one given in Eq. (1), there will be unidirectional coupling between the forward and backward propagating modes and a non-reciprocal Bragg grating (NRBG) results. Here we apply this concept to a Bragg grating supporting long-range surface plasmon polaritons (LRSPPs). The proposed structure offers a single sideband modulation of the refractive index similar to Eq. (1) which gives rise to a non-reciprocal Bragg grating (NRBG). Fig. 1 shows the proposed NRBG architecture. Stepping in width of Ag stripe on Fused silica substrate creates modulation of index of refraction, whereas alternate bricks of doped/undoped PMMA in the top cladding generate modulation of gain/loss. There is a \( \Lambda/4 \) spatial shift between Ag steps in width and PMMA doped/undoped regions which causes a 90° phase shift between index and gain/loss modulation. The device is pumped from top in order to produce gain in the doped regions. Fabrication of this device is ongoing. Electron beam lithography is used for creating Ag and PMMA patterns with features as small as 150 nm. Fig. 2 gives a scanning electron microscope (SEM) image of a Ag step-in-width grating on Fused silica after development and sputtering. The transfer matrix method is used to compute the reflectance and transmittance spectra of the NRBG. Near-ideal non-reciprocal reflectance is predicted along with amplified reflectance in an experimentally realisable structure.
Fig. 1 (a) Proposed NRBG architecture. (b) Top view of the structure. Ag step-in-width metal stripe grating shown in black dashed outline. An undoped/doped PMMA (Poly methyl methacrylate) grating of the same period as the Ag step-in-width grating is overlaid but shifted $\Lambda/4$ spatially with respect to the latter.

Fig. 2 SEM image of a Ag step-in-width grating on Fused silica. The pitch of steps in width is about 300 nm and duty cycle is about 50%.

REFERENCES