Unidirectional Waveguide Grating Antennas for Nanophotonic Phased Arrays

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Abstract: Unidirectional waveguide grating antennas for nanophotonic phased arrays are demonstrated with over 90% directionality. Unidirectional emission eliminates the fundamental problem of element factor blind spots due to reflections of the antenna radiation within the substrate.

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1. Introduction

Recent years have seen increased interest in nanophotonic phased arrays [1-6] for applications including LIDAR and free-space communications. Currently, silicon photonic phased arrays primarily employ optical antennas with near-equal upwards and downwards emission. Not only does this cause loss in output power, downwards emission also undergoes multiple reflections within the silicon substrate, resulting in concentric interference fringes in the element factor [7]. This causes blind spots in the field of view of any steerable phased array that employs optical antennas that emit a significant fraction of light downward into the substrate.

In this work, we present the design and demonstration of a millimeter-scale unidirectional silicon nitride waveguide grating antenna with 93.2% upward directionality to eliminate element factor blind spots. The presented design employs a dual-layer waveguide with periodic inward perturbations that are spatially offset vertically and in the direction of propagation to generate unidirectional emission. While vertically asymmetric perturbations have been shown for achieving unidirectional fiber grating couplers [8], this work is the first demonstration of millimeter-scale unidirectional optical antennas which may be densely arrayed for realizing large-aperture phased arrays similar to [6]. This solves a fundamental problem with the element factor in optical phased arrays and enables high output power.

2. Unidirectional Antenna Design

The dual-layer waveguide grating antenna is comprised of two 200nm thick silicon nitride waveguides, separated by a 100nm gap, with identical inward periodic perturbations. The two waveguide sections are spatially offset along the direction of propagation, as shown in Fig. 1a. The non-perturbed waveguide width is 1μm while the magnitude of the perturbations is adjusted depending on the desired antenna strength. Two scattering points offset in the vertical and horizontal dimensions by $\lambda/4$ result in destructive interference in either the upward or downward radiation and constructive interference in the other, yielding unidirectional emission [9]. However, in this work, the vertical offset was fixed and the upward directionality of the presented dual-layer design was maximized by optimizing the horizontal

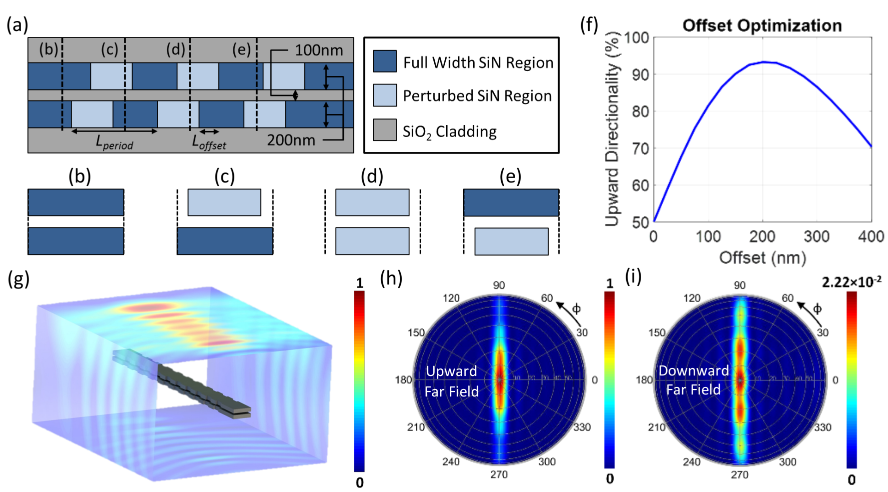

Fig. 1. (a) Side-view schematic of dual-layer unidirectional waveguide grating antenna. (b-e) Antenna cross-sections within a single period. (f) Plot of directionality vs. offset. (g) FDTD simulation of antenna radiation and far fields of the (h) upward and (i) downward emission.

spatial offset of the perturbations between the two layers. As seen in Fig. 1f, upward directionality of 93.2% was achieved with an offset of 210nm. The unidirectionality of the optimized antenna design can be clearly seen in the FDTD simulation shown in Fig. 1g. Furthermore, the corresponding far-fields of the upwards and downward emission when no substrate is included (Fig. 1h-i) show an order of magnitude lower peak power in the downward emission.

3. Element Factor Blind Spot Mitigation and Experimental Results

While the upward emission of a waveguide grating antenna exits the cladding without significant reflection, the downward emission experiences substantial reflections from the SiO_2-Si interface and Si-air interface at the bottom of the substrate (Fig. 2a). This causes high visibility concentric interference fringes to emerge in the element factor (Fig. 2b), as derived in [7]. Optical antennas with high upward directionality may therefore be used to eliminate the appearance of these interference fringes in the element factor. Fig. 2c shows the measured element factor of a single-layer silicon nitride waveguide grating antenna, in which concentric interference fringes appear as expected. Fig. 2d shows the measured element factor of the designed unidirectional antenna. The unidirectional antenna exhibits significantly lower fringe visibility due to the high upward directionality. As further confirmation of antenna unidirectionality, the element factor of an antenna with the same design but fabricated for downward emission was measured (Fig. 2e). As expected, downward emission yields significantly higher fringe visibility since the element factor is defined primarily by the substrate reflections in the presence of minimal direct upward emission. Each of these antennas was 3mm long with a constant perturbation strength along the length of the antenna, resulting in an exponentially decaying near-field radiation profile. An IR camera image of the near-field radiation of the upward emitting antenna is shown in Fig. 2f. A FWHM spot size of 0.05° in the antenna dimension (θ_y) was measured in the far field showing that this antenna can be used to realize large-aperture, small spot size, phased arrays.

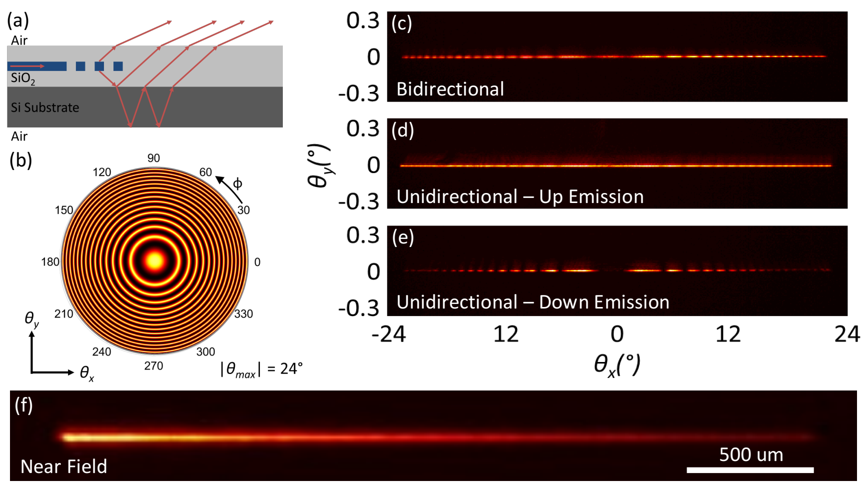

Fig. 2. (a) Schematic of reflections within the substrate due to downward emission and (b) simulation of the resulting concentric interference fringes in the element factor. Measured element factors of (c) single waveguide layer bidirectional antenna and unidirectional antennas with (d) upward and (e) downward emission. (f) Measured near field of unidirectional antenna with upward emission.

4. Conclusion

We have demonstrated the first unidirectional waveguide grating antenna that can be densely arrayed for high-power large-aperture integrated optical phased arrays. Waveguide grating antennas demonstrated in this work were 3mm long with a simulated upward directionality of 93.2%. We show that unidirectional emission mitigates the fundamental problem of the emergence of element factor blind spots due to reflections within the silicon substrate.

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5. References

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