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Plasmonic Nanoantenna for On-chip Optical Phased Arrays

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Abstract: We examine the design, fabrication and radiation chararacteristics of plasmonic nanoantennae in an integrated silicon photonic optical phased array system. Various antenna designs and waveguide feed mechanisms are considered and optimized. Beam formation and active electronic steering and overall system performance are discussed.

Electronic control over the phase of individual radiating elements in an array configuration allows for directional control of the beam formed by their interference pattern. This phase scanning beam-steering effect is widely used in microwave and RF antenna communication systems. It would be highly desirable to scale electronically controlled phased arrays to optical wavelengths using integrated optics. Thus, a CMOS compatible chip-scale transmitter with no moving part would enable new applications such as chip-scale lidar and free-space point to point communication links.

Three basic elements are required for an integrated optical phased array transmitter; 1) a low loss transmission mechanism, 2) a compact phase shifter 3) and an efficient emitting element. In our approach, we use low-loss dielectric waveguides as the feed for our phased array. Compact waveguide thermo-optic phase-shifters are used to electronically control the input phase to our radiating elements. Our radiating elements are plasmonic nanoantenna, patterned sub-wavelength metallic antenna with integrated ground planes. Nanoscale metallic antennae behave very differently in the optical regime compared to the RF. Scaling metallic antennas requires consideration of dispersion and loss, and collective surface resonances at optical frequencies.

Plasmonics is well known to confine light to sub-wavelength length scales and metals are efficient radiators in the optical regime. The enhanced confinement comes at the cost of propagation loss. In analogy with RF transmission lines, metal insulator metal (MIM) waveguides can be used to feed our nanoantenna, however propagation losses can be quite large and limit the length of the MIM feeds. We therefore, use low loss dielectric waveguides to feed our metallic nanoantenna. In this talk, we will focus on design of our plasmonic nanoantenna, in particular efficient coupling methods from dielectric waveguides to highly confined interface and MIM surface plasmons. These coupling methods utilize asymmetric directional coupling from our input dielectric feed waveguides, and depend on the input mode polarization. Depending on antenna-waveguide gap separation, coupling into single interface or MIM surface plasmon modes can occur over distances of ~ 1 micron. Therefore, compact transitions from dielectric waveguides to antenna can be constructed. Furthermore, we will demonstrate our nanoantenna array designs based on MIM fed and aperture based nanoantenna, and show efficient radiation and beam-steering from our chip-scale arrays.

Our waveguide coupled nanoantenna template is illustrated in Fig. 1 (a) which shows a tapered dielectric waveguide between a metallic ground plane and an emitter metal pad. Fig. 1 (b) shows two typical MIM antenna patterns that are transferred to the emitter pad using E-beam lithography. The MIM fed antenna is analogous to a wire antenna structure with characteristic MIM gap between 75-125 nm. The MIM and the input waveguide are both tapered to improve coupling from the dielectric waveguide to the MIM feed, and the metallic ground plane is used to redirect the radiation away from the substrate. The confined current distribution on the thin metal wires and the integrated ground plane give rise to efficient surface normal radiation from the antenna. The area of the radiating element and ground plane is less than 4 microns[2] and together with a compact phase shifter can be combined into an array with period less than 8 microns.

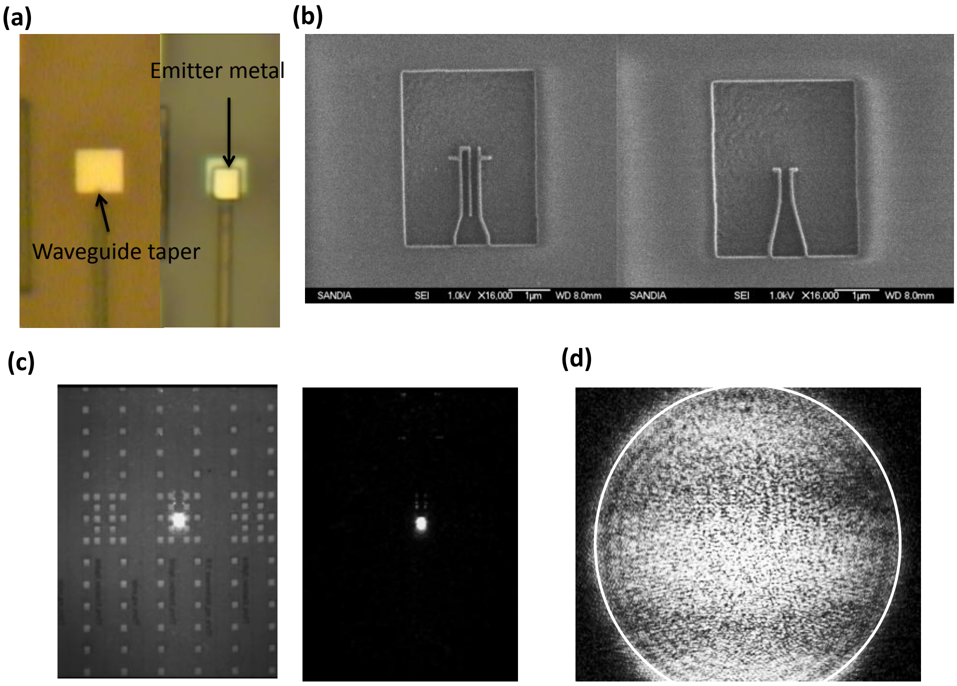

Figure 1 Waveguide fed nanoantenna. **(a)** optical pictures of waveguide fed emitter template. Left image shows waveguide over ground plane, and right image shows emitter metal template above the waveguide and ground plane. **(b)** Two typical MIM fed nanoantenna resist patterns that are transferred to metal emitter. **(c)** Optical images of emission from waveguide fed antenna bright and dark field. **(d)** Fourier plane image of radiation pattern. The circle indicates NA of NIR objective.

Fig. 1 (c) shows the bright field and the dark field near-infrared images of an individual nanoantenna emitter. A low magnification 0.25 NA objective is used to image from the top. Fig. 1 (d) shows the measured Fourier plane of the emitter. This represents the radiation pattern from the MIM fed antenna. Since the size of the antenna is sub-wavelength, we see a nearly uniform pupil fill in the Fourier plane. This corresponds to a nearly isotropic radiation pattern from the emitter. By combining these emitters in 2D arrays, the array function reduces the beam size in the pupil plane.

Recently, several groups have reported 2D optical beam steering using gratings in silicon photonics[1-2]. These devices use wavelength tuning to achieve beam-steering along one axis and integrated phase shifters along another axis. One advantage of the plasmonic approach is that our plasmonic nanoantenna is broadband, and that by tuning the wavelength we can continue to point in a fixed direction in space. This is useful for wavelength division free-space communications applications. Furthermore, it is straightforward to apodize our antenna to improve beam waste, and side lobe suppression.

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References

[1] K. van. Acoleyen, H. Rogier, and R. Baets, *Optics Express.* **18**, 13655 (2010).
[2] J. K. Doylend, M. Heck, J. Bovington, J. Peters, L. Coldren, and J. Bowers, *Optics Express.* **19**, 21595 (2011).