1×256 Multi-layer, low-loss, Si₃N₄ waveguide optical phased arrays with 0.050° Instantaneous-Field-of-View

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Abstract: We report multilayer 1×256 Si₃N₄ optical phased arrays with 8-stage multimode interferometer (MMI) tree. The device shows 4.5 µm mode size, 3 dB excess loss and far field pattern with 0.050° beam width.

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1. Introduction

Optical phased arrays (OPAs) [1, 2] have drawn considerable interest in the past decade for various applications including light detection and ranging (LIDAR), free-space optical communications [3, 4], image projection, holographic displays, and optical switches. In particular, large scale OPAs are desirable because they have narrow beam widths in the far field and therefore concentrate high power in the main lobe and enhance the efficiency. However, the large scale compromises the miniaturization of OPAs, which in turn increases the cost and reduces the accessibility of the device. Implementations in silicon photonic integrated circuits (PIC) can improve the scalability and stability while reducing the size and cost. We recently optimized multilayer Si₃N₄ platform for low-loss and compact PIC [5, 6], making it conducive to large-scale, low-loss OPAs. This paper demonstrates multilayer 1×256 Si₃N₄ OPAs that show 4.5 µm mode field diameter (MFD) at the output edge coupler, 3 dB excess loss and 0.050° instantaneous field of view (IFOV) in the far field.

2. Device fabrication and characterization

Fig. 1 Fabrication process flow consisting of (a) initial cleaning of a 6-inch silicon wafer, (b) LTO deposition, (c) Si₃N₄ bottom layer deposition, (d) Si₃N₄ bottom layer lithography and etching, (e) Inter-layer LTO cladding deposition, (f) CMP, (g) Si₃N₄ top layer deposition, (h) Si₃N₄ top layer lithography and etching, (i) LTO overcladding deposition, (j) CMP, (k) Ti/Au heater lift-off, and (l) heat trench dry etching. (m) Near field MFD measurement by monitoring intensity across the peaks. (n) A photograph of the device. (o) Normalized waveguide transmission to a pair of 2.5-µm MFD lensed fibers vs. waveguide number. Insertion loss is 27-30 dB for 11 measured waveguides.

Fig. 1 (m) illustrates the near field MFD measurement by using an imaging lens after the device and an infrared (IR) camera. The pitch between adjacent waveguides is 30 µm. We fit the measured intensity with Gaussian-shaped curves and calculate the MFD as 4.5 µm. The edge couplers allow small MFD compared to surface grating couplers and create a flat envelope in the far field, allowing a large total field of view (TFOV). Fig. 1(n) is a photograph of
the OPA device. Fig. 1(o) shows the normalized waveguide transmission to a pair of 2.5-µm MFD lensed fibers vs. the waveguide number. We measured 11 waveguides from three sections in a total of 256 waveguides, all of which show 27-30 dB insertion loss. In addition to 24 dB intrinsic loss from 1×256 power splitting, there is 1-dB coupling loss due to the mismatch between 2.5-µm MFD lensed fibers and 4.5-µm waveguide mode. 3 dB excess loss is from 8 MMIs and waveguide propagation loss.

3. Near field and far field measurement

Fig. 2(a) shows the testbed for measuring near field and far field. We use 25-mm and 100-mm lenses for near field measurement, and they provide a 4× magnification ratio. The near field and far field patterns are shown in Fig. 2(b) and Fig. 2(c) respectively. Fig. 2(d) monitors the intensity along the dashed red line in Fig. 2(c) and the separation between two peaks is 0.716˚ based on a calculation given the camera pitch and 200-mm focal length of the third lens. The separation angle is close to the theoretical value arcsin(2λ/4d) = 0.740˚, where the operating wavelength λ = 1.55 µm, 4 is the magnification ratio, and the waveguide pitch d = 30 µm. The IFOV is 0.012˚. The converted IFOV after the elimination of the magnification ratio is 0.050˚. The narrow beam width is a result of large scale 256 OPAs.

In summary, we demonstrate 1×256 OPAs with 4.5 µm MFD, 3 dB excess loss and 0.050˚ IFOV in the far field on a multilayer Si3N4 platform, achieving large scale, low loss, and narrow beam width. Future work includes heterogeneous integration of the PIC with a 3-D waveguide chip fabricated by ultrafast laser inscription (ULI), and realizing optical beam steering by applying electrical currents to the heaters on the top of the Si3N4 waveguides.

4. References


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