CMOS-Compatible Optical Phased Arrays with Monolithically-Integrated Erbium Lasers

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Abstract: An electronically-steerable integrated optical phased array powered by an on-chip erbium-doped laser is experimentally demonstrated. This system represents the first demonstration of a rare-earth-doped laser monolithically integrated with an active CMOS-compatible silicon photonics system.

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1. Introduction to Integrated Optical Phased Array Systems

Integrated optical phased arrays, which manipulate and dynamically steer light with large aperture sizes and fast steering rates, have many wide-reaching applications, including LIDAR, free-space communications, and holographic displays [1–3]. In previous work, phased array systems with on-chip laser sources have been demonstrated using a hybrid III-V/silicon laser integration approach [3]. Compared to these hybrid approaches, monolithically-integrated rare-earth-based lasers [4–6] offer a higher power, more thermally stable, and narrower linewidth approach to on-chip light generation and require a single back-end deposition step which could be performed on the wafer scale.

In this paper, an erbium-doped laser and an electrically-steerable optical phased array are monolithically integrated in an active CMOS-compatible silicon photonics platform. This system represents the first demonstration of an active CMOS-compatible silicon photonics system powered by a rare-earth-doped monolithically-integrated laser and paves the way for future monolithic systems, such as data communication links and on-chip optical synthesizers.

2. Monolithically-Integrated Phased Array System Architecture

The monolithically-integrated system is fabricated at CNSE SUNY-Poly in a CMOS-compatible silicon photonics platform consisting of two silicon-nitride layers, a silicon layer with eight doping levels, three metal and via layers, and a trench for deposition of an erbium-doped aluminum oxide ($Al_2O_3{:}Er^{3+}$) film (performed at MIT). Figure 1a shows a simplified schematic of the system.

The system uses an on-chip distributed feedback (DFB) laser (similar to [5]). The 2-cm-long gain waveguide of the DFB laser consists of five silicon-nitride segments underneath a $Al_2O_3{:}Er^{3+}$ film. The widths of and gaps between the silicon-nitride pieces are designed to ensure high mode overlap and confinement within the gain film for both the 980-nm-wavelength pump and 1599-nm-wavelength signal. The 1170-nm-thick film is deposited within the 30-µm-wide trench via reactive co-sputtering. A 397°C deposition temperature is chosen to ensure that the metal vias do not degrade due to the deposition process [6]. The DFB cavity is formed by adding a silicon-nitride grating with a central gap along both sides of the gain waveguide to enable a single-mode lasing output.

At the far end of the DFB, a layer transition is designed to adiabatically couple the mode from the gain waveguide into a double-layer silicon-nitride waveguide. The signal wavelength is then separated from the pump using a wavelength-dependent directional coupler acting as a wavelength-division multiplexer (WDM) and connected to the input silicon bus of the integrated phased array using another layer transition.

The integrated phased array consists of a grouped cascaded phase shifter architecture which controls the relative phase applied to an array of antennas (architecture similar to [2]). Evanescent couplers with increasing coupling lengths are used to uniformly distribute the input power from the bus waveguide to 49 grating-based 500-µm-long antennas with a 2 µm pitch. A doped waveguide-embedded thermal phase shifter is placed on the bus between each coupler to enable cascaded phase control to the antennas for 1D beam steering. The phase shifters are grouped and controlled by 6 electrical signals to reduce complexity while enabling fine tuning for any fabrication-induced phase variations. Given the 0.5 mm by 0.1 µm aperture size and 2 µm antenna pitch, a 0.80° by 0.16° main beam full-width half-maximum and grating lobes at ±51° are expected in the far field of the array when the main beam is centered at 0°.

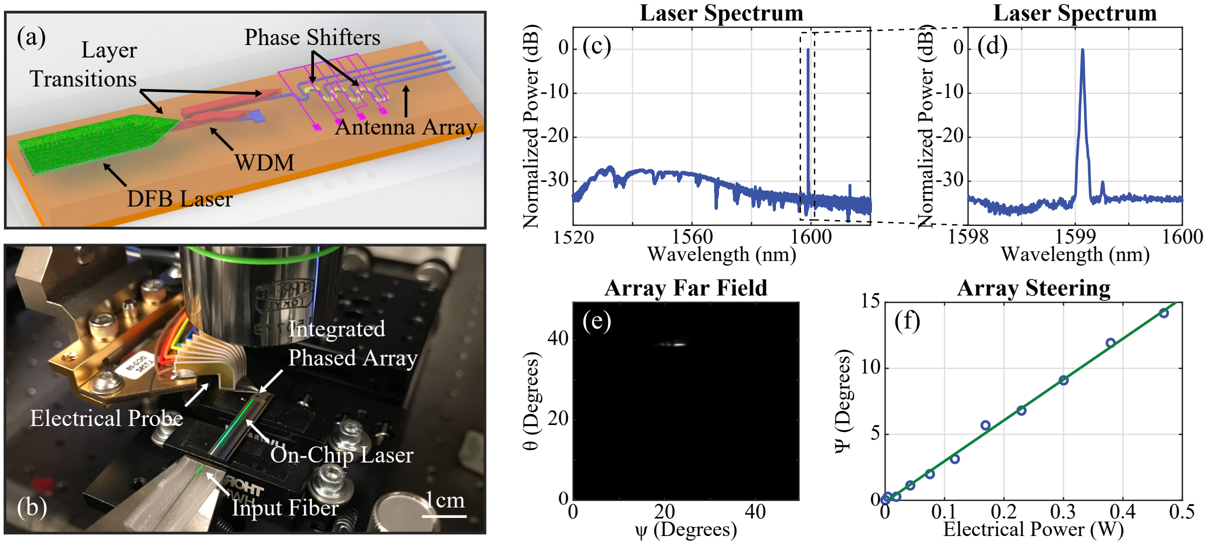

Fig. 1. (a) Simplified schematic of the phased array system with an on-chip laser showing major components and process layers (pump not shown and not to scale). (b) Photograph of the experimental setup. Measured optical spectrum of the on-chip laser showing (c) the full spectrum including amplified spontaneous emission and (d) the lasing peak at 1599 nm. (e) Measured far field above the system showing the main lobe of the phased array. (f) Experimental results showing beam steering in the array dimension, ψ, versus applied electrical power.

3. Laser Spectrum and Electrical Beam Steering Experimental Results

To characterize the fabricated system, an off-chip 980-nm-wavelength pump is coupled into the on-chip laser with 254 mW of optical power launched from the input fiber facet, as shown in Fig. 1b. Figures 1c–d show the normalized measured laser spectrum. A single lasing peak at 1599 nm with a 30 dB side-mode suppression ratio (SMSR) is observed. Next, a free-space optical setup is utilized to image the far field of the phased array onto an InGaAs IR camera, as shown in Fig. 1e. As expected, the system forms a collimated beam in the far field of the array within the 50° field of view of the imaging objective. A multi-pin electrical probe is used to apply electrical power across the integrated phase shifters and steer the beam in the far field. With 0.5 W of applied electrical power, 15° of steering in the array dimension, ψ, is observed, as shown in Fig. 1f. This closely matches the thermal steering efficiency previously observed [2], confirming that the film deposition procedure does not detrimentally affect the via integrity.

4. Conclusions and Anticipated Applications of the Integrated System and Monolithic Platform

An electrically-steerable optical phased array with a monolithically-integrated laser source has been shown at 1599 nm wavelength with a 30 dB SMSR and 15° electrical beam steering. This system enables integrated CMOS-compatible beam steering capabilities for a variety of applications, ranging from LIDAR to free-space communications. Additionally, this work represents the first demonstration of a monolithic rare-earth-doped laser source integrated with an active CMOS-compatible silicon photonics system. The successful realization of such a system paves the way for future monolithic silicon photonics demonstrations, ranging from communication links to on-chip optical synthesizers.

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