Assembly of III-V Microdisk Lasers on Silicon Using Lateral-Field Optoelectronic Tweezers

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Abstract A room-temperature optofluidic assembly process to integrate III-V microdisk lasers on a silicon chip is demonstrated. The assembly is accomplished using lateral-field optoelectronic tweezers, which achieves a placement accuracy of approximately ± 0.25 μm.

Introduction

Silicon photonics enables intimate integration of CMOS electronics and optoelectronic components. However, a challenge is the integration of semiconductor lasers on silicon. Silicon Raman lasers [1, 2] require external optical pumps. The growth temperature of heteroepitaxy (> 400^{o}C) is usually too high for post-CMOS processing [3]. Low-temperature (300ºC) wafer bonding techniques [4] present additional challenges on fully-processed CMOS wafers, as the silicon bonding surfaces are buried underneath layers of electrical interconnects. We demonstrate an optofluidic device capable of integrating thin (0.2 μm), compact (5 to 10 μm in diameter) III-V microdisk lasers on patterned Si wafers in a room-temperature post-CMOS process. The assembly process is realized using lateral-field optoelectronic tweezers (LOET), and enables the integration of compound semiconductor components with CMOS circuits.

Assembly of III-V Microdisk Lasers on Silicon

Multiple quantum-well III-V microdisk lasers are fabricated on III-V wafers, released in solution, and assembled on silicon pedestals using LOET. The LOET is directly fabricated on a Si wafer, and consists of an array of interdigitated photosensitive electrodes of amorphous silicon (a-Si) (Fig. 1a). Silicon pedestals are centered in the 5-μm-wide gaps between the LOET electrodes.

The LOET electrodes create an optically-induced dielectrophoretic force, which is controlled by voltage applied across the electrodes and the position of optical patterns on the light-sensitive a-Si layer [5]. The highest forces are in the illuminated areas near the electrode edges (Fig. 1b). Microdisks are attracted to the illuminated areas, and self-align in the gap between the electrodes. Moving the optical patterns allows transportation of the microdisks along the length of the electrodes. Once the disks are aligned over a pedestal, the applied voltage is increased to hold the disks in place as the solution dries. Ethanol is used to minimize surface tension forces during drying. After drying, the a-Si layer is removed by XeF_2 etching at 40^{o}C to prevent interfering with the optical mode of the microdisk. The disks are aligned with an accuracy of approximately ± 0.25 μm (Fig. 2a). This can be further improved by optimizing the optical imaging system.

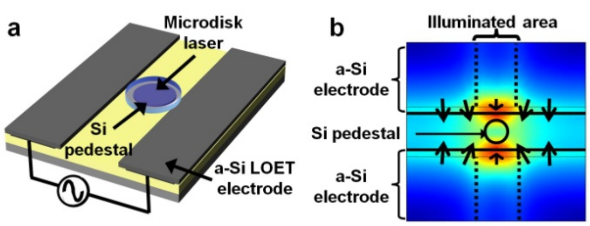

Fig. 1 (a) Schematic of integrated LOET for microdisk laser assembly. The LOET electrodes allow optical patterns to control the assembly of III-V microdisks on silicon pedestals. (c) Finite-element simulation of the electric field profile across the LOET electrodes. The arrows show the direction of the optically-induced force.

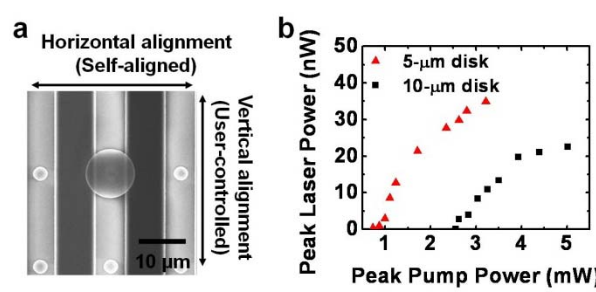

Fig. 2. (a) An assembled 10-μm-diameter microdisk. (b) Peak laser power versus peak pump power. The threshold pump powers for 5- and 10-μm-diameter disks are 0.85 mW and 2.5 mW, respectively. The actual optical power is higher since only scattered light from the top of the disk is measured.

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The assembled microdisk lasers are optically pumped by 0.5-μs pulses with a 20-kHz repetition rate (1% duty cycle) using a 780-nm diode laser. At room temperature, the 5- and 10-μm-diameter microdisks achieve single-mode lasing at wavelengths of 1559 nm and 1586 nm, at threshold pump powers of 0.85 mW and 2.5 mW, respectively (Fig. 2b).

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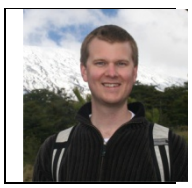

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