Hybrid Microdisk Laser on a Silicon Platform Using Lateral-Field Optoelectronic Tweezers Assembly

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Abstract: An InGaAs/InGaAsP microdisk laser is assembled on silicon using lateral-field optoelectronic tweezers, achieving room-temperature pulsed operation with a threshold power of 0.85 mW. The room-temperature assembly enables a post-CMOS process to fabricate micro-lasers on silicon.

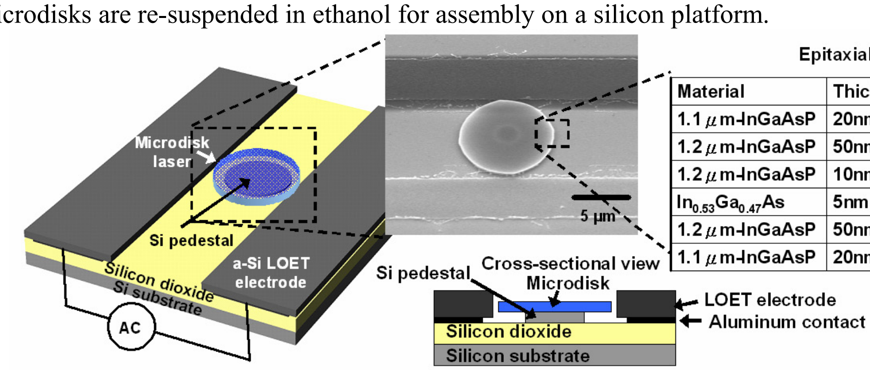
OCIS codes: (140.5960) Semiconductor lasers; (350.4855) Optical tweezers or optical manipulation; (170.4520) Optical confinement and manipulation; (250.5590) Quantum well, -wire and -dot devices

1. Introduction

Semiconductor lasers on silicon chips have attracted much attention due to the potential of integration with CMOS integrated circuits. Silicon Raman lasers have been demonstrated [1,2], however, they still require external optical pumps. Electrically-pumped AlGaInAs-silicon hybrid lasers utilizing oxygen plasma-assisted wafer bonding have been demonstrated [3]. The low bonding temperature (300°C) enables post-CMOS integration, however, the silicon layer to which the laser wafer bonds is buried under a thick stack of interconnect layers. Though bonding windows can be opened by etching, the nonplanar topography presents additional challenges for wafer bonding. In this paper, we propose an alternative approach: microdisk lasers are fabricated first on InP substrate and then released in a solution. They are subsequently assembled on a silicon platform using lateral-field optoelectronic tweezers (LOET). Experimentally, we have demonstrated room temperature operation of a 195-nm-thick, 5-µm-diameter InGaAs/InGaAsP microdisk laser on silicon pedestals with a threshold pump power of 0.85 mW. This technology enables a room-temperature, post-CMOS process to integrate micro-lasers on silicon.

2. Microdisk Fabrication and Assembly

An InGaAs/InGaAsP multiple-quantum-well (MQW) epitaxial structure with a photoluminescence peak at 1550 nm is used to fabricate microdisk lasers. The MQW layers are sandwiched by two symmetrical larger-bandgap optical confinement layers. The total thickness of the active layers is 195 nm. The detailed epitaxial structure of active layers is shown in Fig. 1. Microdisk fabrication is achieved by etching the active layers using 0.5% Br_2 in methanol, followed by the release of the microdisks by etching an InP sacrificial layer using a diluted HCl solution. The microdisks are re-suspended in ethanol for assembly on a silicon platform.



Epitaxial Layer Structure

Material	Thickness	Description
1.1 µm-InGaAsP	20nm	Optical confinement layer
1.2 µm-InGaAsP	50nm	Optical confinement layer
1.2 µm-InGaAsP	10nm x4	4-layer barriers
$In_{0.53}Ga_{0.47}As$	5nm x3	3-layer wells
1.2 µm-InGaAsP	50nm	Optical confinement layer
1.1 µm-InGaAsP	20nm	Optical confinement layer

Fig. 1. Schematic of integrated lateral-field optoelectronic tweezers (LOET) for microdisk laser assembly. The layers of the 195-nm-thick microdisks are listed in the table. The microdisks are assembled onto silicon pedestals using LOET. The inset shows an SEM image of an assembled microdisk.

Microdisk lasers are created by assembling the fabricated microdisks on silicon pedestals using LOET [4]. The LOET device is integrated on the same substrate as the Si pedestals (Fig. 1), enabling optically-controlled trapping, transport, and assembly of the microdisks onto the pedestals by optically-induced dielectrophoresis [4]. The microdisks are attracted to the optical patterns projected onto the LOET electrodes, allowing controlled assembly (Fig. 2).

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The fabricated microdisks, suspended in ~90% ethanol, are pipetted onto the substrate. The optical patterns are created from the output of a computer projector, and focused onto the substrate by a 20× objective lens. An AC voltage of 1 to 10 Vpp at 200 kHz is applied to the LOET electrodes to generate the trapping force, and the optical pattern is scanned to move randomly-positioned microdisks over the Si pedestals. Once the disks are aligned over a pedestal, the applied voltage is increased to 20Vpp to hold the disk in place as the liquid solution dries. After drying the a-Si layer is removed by xenon difluoride etching, so the a-Si electrodes do not interfere with the optical mode of the microdisk.

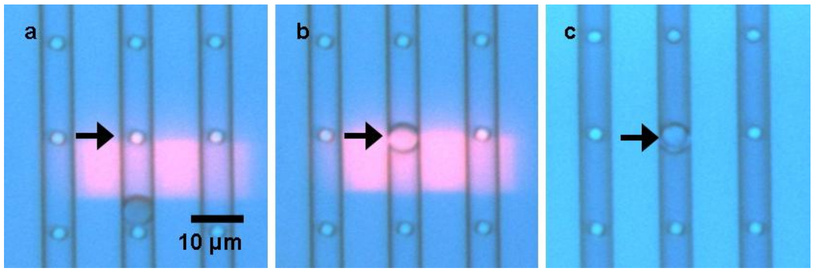

Fig. 2. Assembly of III-V microdisks onto 3-μm-diameter silicon pedestals using lateral-field optoelectronic tweezers. (a) The initial position of a 5-μm-diameter microdisk. The optical trapping pattern, generated by a computer projector, is visible as a red rectangle. The microdisk is attracted towards the trapping pattern by optically-induced dielectrophoretic force. The Si pedestal that is used for assembly is indicated by the arrow. (b) The microdisk is positioned over a Si pedestal. The trapping force is then increased to immobilize the disk on the substrate. (c) The assembled microdisk remains in place after the liquid solution has dried.

3. Optical Measurements

The assembled microdisk lasers are optically pumped at room temperature (18°C) by 0.5-μs pulses with a 20 kHz repetition rate (1% duty cycle) using a 780-nm diode laser. The pump beam is focused onto the disk through a 40× objective, resulting in a beam size of 3 μm. The emitted light is collected through the same objective and then filtered by a 900 nm-long-pass optical filter to block the light from the pump laser. The filtered optical signal is coupled to a multimode fiber, and the output spectrum is measured by an optical spectrum analyzer (OSA).

The measured lasing spectra for 5-μm-diameter and 10-μm-diameter microdisks on Si pedestals after LOET assembly are shown in Fig. 3(a) with lasing wavelengths of 1558.7 nm and 1586 nm, and linewidths of 1.05 nm and 1.2 nm, respectively (OSA resolution bandwidth: 1nm). Both lasers exhibit single mode operation under pulsed excitation. The average laser power at the lasing wavelength versus peak pump power is shown in Fig. 3(b), where the threshold pump powers for 5-μm and 10-μm microdisk lasers on Si pedestals are 0.85 mW and 2.5 mW, respectively. The 5-μm-diameter microdisk laser has a lower threshold pump power due to the smaller mode volume. Heating of the microdisk lasers eventually limits the output power when the pump powers exceed 2 mW and 4 mW for 5-μm and 10-μm microdisks on Si pedestals, respectively. It should be mentioned that there is a 3-μm-thick buried oxide layer underlying Si pedestals, increasing the thermal resistance. Therefore, for microdisks on InP pedestals before releasing and assembly, the power saturation is not as obvious as those on Si pedestals. As shown in Fig. 3(b), the threshold pump powers of the microdisk lasers before and after LOET assembly are comparable, indicating that the microdisks are not damaged during the assembly procedure.

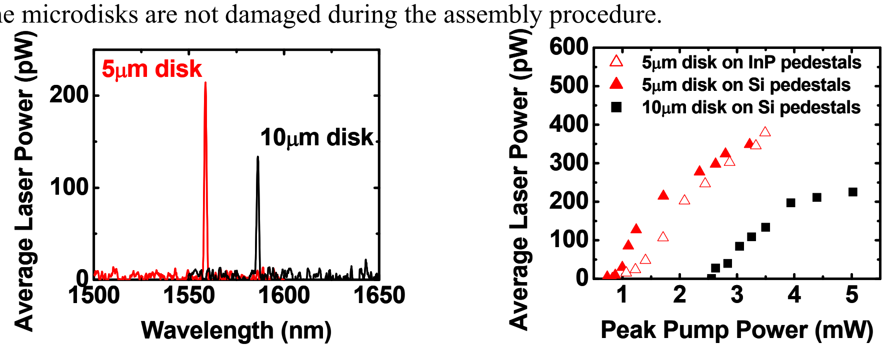

Fig. 3. (a) Lasing spectra for 5-μm-diameter and 10-μm-diameter microdisk lasers on Si pedestals under pulsed excitation The pump power for these two spectra are 1.7 mW for the 5-μm disks and 3.5 mW for the 10-μm disks. (b) Average laser power versus peak pump power. The threshold pump powers for 5-μm and 10-μm disks are 0.85 mW and 2.5 mW, respectively.

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