Tunable III-V-on-Si Laser with Resonant Photonic Molecule Mirrors

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We propose, fabricate and characterize a novel III-V-on-Si laser. Resonant mirrors are realized by tailoring supermodes of coupled microrings. A threshold of 40mA, series resistance of 10 Ω and SMSR of 40dB is reported.

OCIS codes: (140.5960) Semiconductor lasers, (230.4555) Coupled resonators , (140.3600) Lasers, tunable

1. Introduction and Discussion

Heterogeneous integration of III-V materials on top of Si waveguides has become one of the most efficient methods for incorporating semiconductor lasers onto a Si photonic platform [1]. The maturing of different techniques for III-V-on-Si laser integration, e.g. BCB adhesive bonding [2], direct bonding [3] and transfer printing [4], has led to a myriad of laser devices relying on both high optical gain of III-V materials and low-loss, high index contrast and small footprint SOI waveguide circuits. The use of Si microring resonators for modal filtering and feedback to form a laser cavity has been demonstrated in several forms, see e.g. [2].

Here we present a novel design of a ring resonator based III-V-on-Si laser, where each mirror is realized by a system of coupled resonators composed by an outer ring coupled to two embedded rings mutually coupled, here called a photonic molecule. Figure 1(a) shows a sketch of the proposed idea. When all rings are on resonance, the mutual coupling of this odd number of resonators results in standing wave supermodes of the molecule due to the breaking of degeneracy between clockwise (CW) and counterclockwise (CCW) bare modes of the microrings [5]. If any of the rings is tuned out of resonance or if a different resonant order is chosen (in which case the Vernier effect forces the detuning between cavities), this phenomenon disappears. Seen from a bus waveguide coupled to the outer ring, the breaking of the degeneracy appears as an induced reflection which can be tailored according to a balance between coupling strength and detuning (Figure 1(c) and (d)).

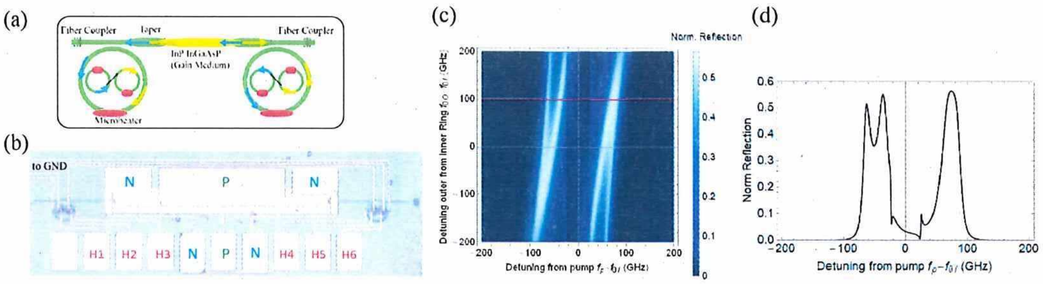

Fig. 1: (a) Schematics of the proposed laser structure with a pair of photonic molecule mirrors. Light propagating in CW direction (orange) is forced to couple to CCW direction (blue). The gain medium (yellow) in between the mirrors is bonded on the silicon waveguide circuit and tapers are used for coupling to the Si waveguide structure. (b) Micrograph of the fabricated device, with contact pads depicted: H1 to H6: microheaters pads; N: N-contact and P: P-contact of diode laser. All heaters share a common ground pad (not shown). (c) and (d) Simulated reflection for the photonic molecule around the maximum degeneracy. In (c), each horizontal line (e. g. red line) represents a reflection spectrum of a molecule for a given detuning (vertical axis) between the outer ring and degenerated inner rings.

The device fabrication is based on DVS-BCB adhesive bonding of an InP 1550 nm amplifier stack on a 400 nm SOI e-beam patterned wafer. The detailed fabrication is reported in [2]. Optical coupling between the III-V amplifier and the silicon photonic integrated circuit is realized by means of a double inverted taper. Figure 1 (b) shows a typical fabricated device where each ring out of the photonic molecule has an integrated TiAu microheater for tunability. Gold pads allow biasing both the amplifier and the microheaters.

Laser basic characterization is depicted in Figure 2. The current-voltage curve is depicted in Figure 2 (a). A series resistance of 10 Ω is extracted. A laser threshold current of 40 mA is achieved (1.5V bias) as shown in Figure 2(b). Laser emission at 1571 nm is observed as depicted in Figure 2(c). Under higher biases, and higher optical power, mode hopping to the closest lower wavelength supermode is observed. We attribute this mode hopping to a difference of distribution of optical power inside each microring in both mirrors, leading to an effective detuning due to the strong thermo-optical effect in silicon and, thus, to a new supermode condition. A waveguide-coupled output power of -3 dBm and a 40dB side mode suppression ration (SMSR) is obtained.

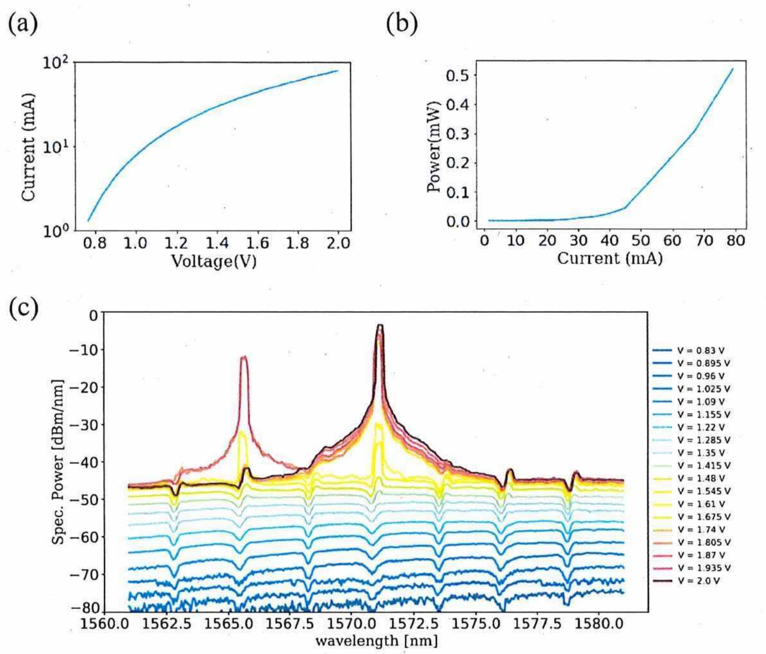

Fig. 2: (a) Current-voltage curve. For high bias voltages, a 10 Ω series resistance is obtained. (b) waveguide-coupled optical power, showing a threshold current of 40 mA. (c) Optical spectrum for various amplifier bias voltages. The laser operates at 1571 nm, with a SMSR of 40dB

2. Conclusion

We demonstrate a novel III-V-on-Si laser based on photonic molecule resonant mirrors. Basic characterization shows a threshold of 40mA with -3 dBm waveguide-coupled output power at 1571 nm and a SMSR of 40dB.

3. Acknowledgment

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References

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Marriott Salon I & II	Marriott Salon III	Marriott Salon IV

Joint

13:00–15:00
JTu3M • Symposium on Intense-field Nonlinear Optics & High Harmonic Generation in Nanoscale Materials I
Presider: To Be Announced

JTu3M.1 • 13:00 Invited
Extreme Nonlinear Optics With Dielectric Metasurfaces, Igal Brener[1]; [1]*Sandia National Labs Livermore, USA.* We have used dielectric metasurfaces made from direct bandgap semiconductors to generate high harmonics and nonlinear mixing simultaneously, without the need of phase matching. Inclusion of broken-symmetry designs and quantum heterostructures can lead to even higher efficiency.

JTu3M.2 • 13:30 Invited
Enhancement of Nonlinear Processes by Surface Plasmons, Pierre Berini[1]; [1]*Univ. of Ottawa, Canada.* Nonlinear processes using nanoscale metallic structures are of strong interest due to their ability to enhance local fields and engineer the optical density of states. We discuss various nonlinear processes that exploit these effects.

JTu3M.3 • 14:00
Coherent Control of the Non-instantaneous Response of Plasmonic Nanostructes, Eyal Bahar[3,2], Uri Arieli[3,1], Haim Suchowski[3,1]; [1]*Condenst Matter Physics., Tel Aviv Univ., Faculty of Exact Sciences, Israel;* [2]*Condenst Matter Physics., Faculty of Exact Sciences, Tel Aviv Univ.., Israel;* [3]*The Center for Light-Matter Interaction, Faculty of Exact Sciences, Tel Aviv Univ., Israel.* We experimentally demonstrate coherent control of the nonlinear response of resonant nanostructures beyond the weak-field regime. Furthermore, we develop a novel theoretical approach capturing the induced nonlinearities of shaped ultrafast pulses with resonant nanostructured media.

CLEO: Science & Innovations

13:00–15:00
STu3N • Lasers on Silicon & Nanolasers
Presider: Kei May LAU, Hong Kong University of Science and Technology, Hong Kong

STu3N.1 • 13:00
Triple reduction of threshold current for 1.3 μm InAs quantum dot lasers on patterned, on-axis (001) Si, Chen Shang[1], Yating Wan[1], Justin Norman[1], Daehwan Jung[1], Qiang Li[2], Kei May Lau[2], Arthur Gossard[1], John Bowers[1]; [1]*Univ. of California Santa Barbara, USA;* [2]*Hong Kong Univ. of Science and Technology, Hong Kong.* Triple reduction of threshold current was achieved for 1.3 μm InAs quantum dot lasers on patterned, on-axis (001) Si. This was enabled by reducing the threading dislocation density, from $7x10^7$ to $3x10^6$ cm^{-2}.

STu3N.2 • 13:15
Tunable III-V-on-Si Laser with Resonant Photonic Molecule Mirrors, Guilherme F. de Rezende[1,2], Newton Frateschi[1], Gunther Roelkens[2]; [1]*"Gleb Wataghin" Physics Inst., Universidade Estadual de Campinas, Brazil;* [2]*Photonics Research Group, INTEC, Ghent Univ.-imec, Belgium.* We propose, fabricate and characterize a novel III-V-on-Si laser. Resonant mirrors are realized by tailoring supermodes of coupled microrings. A threshold of 40mA, series resistance of 10 Ω and SMSR of 40dB is reported.

STu3N.3 • 13:30
Investigation of SiGeSn/GeSn/SiGeSn Quantum Well Structures and Optically Pumped Lasers on Si, Yiyin Zhou[1,2], Joe Margetis[4], Grey Abernathy[1,2], Wei Dou[1], Perry Grant[1,2], Bader Alharthi[1], Wei Du[5], Alicia Wadsworth[6], Qianying Guo[6], Huong Tran[1,3], Solomon Ojo[1,2], Aboozar Mosleh[7], Seyed Ghetmiri[7], Gregory Thompson[6], Jifeng Liu[8], Greg Sun[9], Richard Soref[9], John Tolle[4], Baohua Li[3], Mansour Mortazavi[7], Shui-Qing Yu[1]; [1]*Dept. of Electrical Engineering, Univ. of Arkansas, USA;* [2]*Microelectronics-Photonics Program, Univ. of Arkansas, USA;* [3]*Arktonics, LLC, USA;* [4]*ASM, USA;* [5]*Dept. of Electrical Engineering, Wilkes Univ., USA;* [6]*Dept. of Metallurgical and Materials Engineering, Univ. of Alabama, USA;* [7]*Dept. of Chemistry and Physics, Univ. of Arkansas at Pine Bluff, USA;* [8]*Thayer School of Engineering, Dartmouth College, USA;* [9]*Dept. of Engineering, Univ. of Massachusetts Boston, USA.* SiGeSn/GeSn/SiGeSn single and multiple quantum well (MQW) structures were characterized. The SiGeSn barriers provide a strong carrier confinement with sufficient barrier height, leading to the lasing with MQW device up to 90 K.

STu3N.4 • 13:45
O-band InAs/GaAs Quantum Dot Micro-disk Lasers on SOI by in-situ hybrid epitaxy, Bin Zhang[1], Wei W. Qi[1], Ting Wang[1], Jianjun Zhang[1]; [1]*Inst. of Physics, China.* By implementing III-V/Si hybrid growth technique, we demonstrate the first InAs quantum-dot micro-disk laser on SOI substrates. Threshold pμmp power as low as 0.39 mW were achieved with the Q factor of 3900.

STu3N.5 • 14:00
Spatially Coherent Interlayer Exciton Lasing in an Atomically-Thin Heterostructure, Eunice Paik[1], Long Zhang[1], William Burg[2], Rahul Gogna[1], Emanuel Tutuc[2], Hui Deng[1]; [1]*Univ. of Michigan, USA;* [2]*Univ. of Texas, USA.* We demonstrate lasing in WSe_2-$MoSe_2$ heterostructure integrated in a silicon nitride grating cavity. Signatures of lasing include sharp increase in spatial coherence and super-linear increase in the emission intensity as photon number increases above unity.

13:00–15:00
STu3O • Emerging Visible Light Communication
Presider: Qiaoqiang Gan, State Univ. of New York at Buffalo, USA

STu3O.1 • 13:00 Tutorial
Visible-light Diode-lasers and Integrated Photonics for Lighting and High-bitrate Visible Light Communication, Boon S. Ooi[1]; [1]*King Abdullah Univ of Sci & Technology, Saudi Arabia.* The advent of AlInGaN-based devices operating in the violet to green visible-wavelength range has ushered in high performance solid-state lighting and gigahertz visible-light communication (VLC). In this tutorial, we will discuss the recent advances.

Boon S. Ooi (Fellow of OSA, SPIE, and IoP; Ph.D. degree from the University of Glasgow, UK, 1994) joined King Abdullah University of Science and Technology (KAUST) in 2009, from Lehigh University (USA). His group focuses on lasers for solid-state lighting, visible-light and underwater-wireless-optical communication, and nanostructures for energy harvesting.

STu3O.2 • 14:00
Integrated Silicon Photodetector in Thin Film Lithium Niobate Platform for Visible Wavelength Band, Boris Desiatov[1], Marko Loncar[1]; [1]*Harvard Univ., USA.* We demonstrate design, fabrication and characterization of amorphous silicon photodetector on lithium niobate photonic platform at visible wavelengths. The device shows the best responsivity of 10mA/W and dark current of less than 0.5nA.