Microlasers for photonic switching and interconnection

Yong H. Lee, Jack L. Jewell, Juergen Jahns, Axel Scherer, James P. Harbison, et al.

Yong H. Lee, Jack L. Jewell, Juergen Jahns, Axel Scherer, James P. Harbison, Leigh T. Florez, "Microlasers for photonic switching and interconnection," Proc. SPIE 1319, Optics in Complex Systems, (1 July 1990); doi: 10.1117/12.34928

Event: 15th International Optics in Complex Systems, 1990, Garmisch, Germany

Microlasers for photonic switching and interconnection

Y.H. Lee, J.L. Jewell, J. Jahns

AT&T Bell Laboratories, Holmdel, NJ 07733, USA

A. Scherer, J.P. Harbison, and L.T. Florez

Bellcore, Red Bank, NJ 07701, USA

Vertical-cavity, surface-emitting lasers have great potential owing to their inherent two-dimensional geometry and very small gain medium volumes which are essential to low threshold currents. Possible applications are optical switching/computing, photonic interconnection, high/low power laser sources, image processing, optical neural networks, etc. Driven by these high promises, there have been numerous reports on vertical cavity surface emitting laser diodes using InGaAs/GaAs/AlAs, GaAs/AlGaAs structures[1-6]. In this paper, we report characteristics of discrete InGaAs microlasers and monolithic two-dimensional arrays of microlasers. The advantages of optics for communications of data over distances longer than nearby gates have been argued previously[7]. We proposed and demonstrated a photonic interconnect scheme using microlasers with planar optics which will be robust, accurate, and easily alignable.

We made various sizes (1.5-100 μm) of electrically-driven vertical cavity surface emitting microlasers on a single GaAs chip. The active lasing medium is $In_{0.2}Ga_{0.8}As$, only 100-Å (single quantum well, SQW) or 240-Å (three quantum well, 3QW) thick, located at the central optical intensity peak of the laser cavity. Unlike conventional edge-emitting laser diodes, these microlasers emit light (960-990 nm) perpendicular to crystal growth planes, through the semi-transparent n-doped GaAs substrates. The basic structure is a vertical *pin* junction where electrical current is injected through the bottom (output) and top (end) mirrors. Both bottom (n-doped) and top (p-doped) mirrors are highly reflective (>99.7 %) quarter-wave stacks of GaAs and AlAs layers, to compensate extremely small optical gain from very thin active gain medium. The whole microlaser structures are grown by precisely controlled molecular beam epitaxy. After standard contact lithography and liftoff which created Ni masks, the microlasers are formed as mesas (3-7 μm deep) by chemically-assisted ion beam etching. Detailed information about the structure and etching will be found elsewhere.[4-6]

Experiments were performed at room temperature. Minimum continuous wave threshold current of 1.5 mA is achieved without heatsinking, from 5-μm square SQW microlasers, with 5 V. Minimum pulsed threshold was 1.1 mA with 5-μm diameter microlasers. A 7-μm diameter 3QW microlasers had cw threshold 2.5 mA at 4 V and output over 0.3 mW with 6 mA current. The cw laser linewidth was measured to be 0.1 Å, using a scanning Fabry-Perot etalon. The measured single facet differential quantum efficiencies were 7-28 %, depending on sizes, etching depths, and structures. Also, maximum pulsed peak output of >170 mW (average 4 mW) output was obtained from a 100-μm square device. In most of the chips tested, the microlasers have yields of better than 95 %. It was also demonstrated that these microlasers can be modulated at multi-GHz rates. In present form, threshold current densities are still higher than the theoretical values[8] by more than an order of magnitude. Therefore, there is still much room for improvement with proper passivation of side walls of etched mesas to minimize surface recombination combined with improved laser designs.

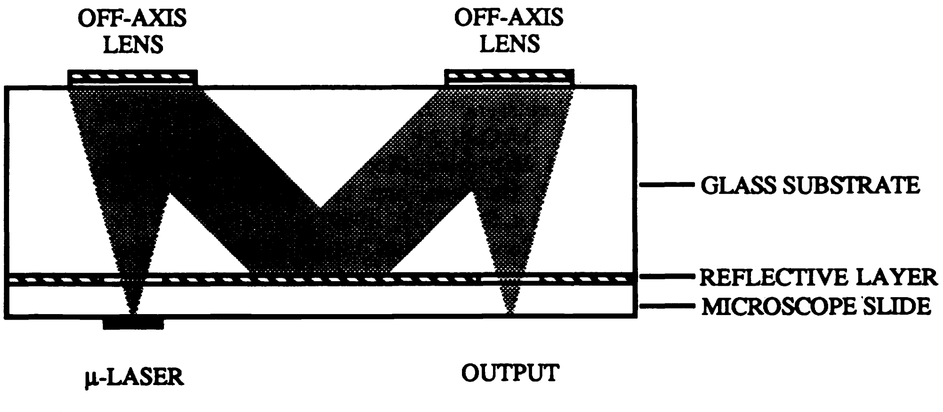

Fig. 1 Configuration of planar optics and microlasers used in the experiment.

Simultaneous operation of a 5x3 array of microlasers was demonstrated. The array is made by chemically assisted ion beam etching followed by polyimide planarization and Au coating. Only 13 microlasers are lasing (two of them are disconnected or mechanically destroyed). Individual microlasers are 5x5 μm square mesas with threshold currents of about 2 mA. Therefore, about 30 mA is needed to operate 13 microlasers at the same time. All 13 microlasers are driven by a single pulse generator using pulse train of 2 % duty cycle. Due to small variation in threshold currents and series resistances, some microlasers turned on at slightly lower driving voltages than the others. But above threshold, arrays looked fairly uniform .

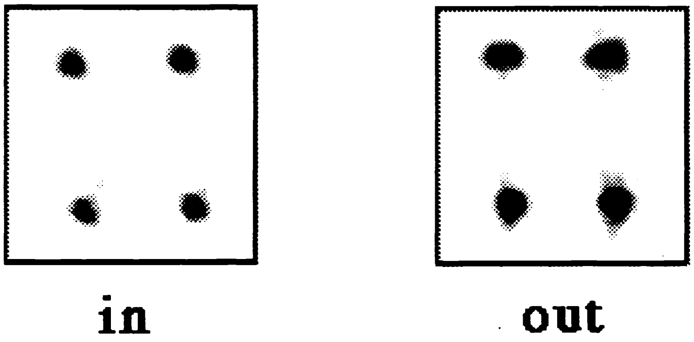

Fig. 2 Images of input and output of a 2x2 microlaser array through planar optics shown in Fig. 1.

A microlaser array (2x2 array) is combined with planar optics to demonstrate the simplicity and potential of photonic interconnection. Planar optics[9] consists of Fresnel lenses and gratings patterned on one or two surfaces of plane parallel glass or quartz plates. Since the mask patterns are generated by an electron beam mask machine, the relative positioning (alignment) accuracy of the imaging system (two off-axis Fresnel lenses and a reflector are shown in Fig. 1) can be easily better than one micron. Fig. 2 (in) and (out) are the images of input microlaser array and output microlaser array through the planar optics, respectively.

In summary, we made various sizes of low threshold surface emitting microlasers and their 2-D arrays successfully. Also, we demonstrated a photonic interconnection scheme using the 2x2 microlaser array and planar optics. The combined configuration will be robust, accurate, and easily alignable. Therefore, the system could be easily incorporated with electronic circuitries and optical switching/computing systems.

REFERENCES

1. F. Koyama, S. Kinoshita, and K. Iga, "Room temperature cw vertical cavity surface emitting laser and high power 2-D laser array," *Tech. Digest of OSA Conf. on Lasers and Electro-Optics*, paper FC1, 380 (1989).
2. D. Botez, L. Zinkiewicz, T.J. Roth, L.J. Mawst, and G. Peterson, "Low-threshold-current-density Vertical-cavity Surface Emitting AlGaAs/GaAs Diode Lasers," *IEEE Photon. Technol. Lett.* **24**, 52-54, 1989.
3. K. Tai, R.J. Fisher, C.W. Seabury, N.A. Olsson, T-C. D. Huo, Y. Ota, and A.Y. Cho, "Room-Temperature Continuous-wave Vertical Cavity Surface Emitting GaAs Injection Lasers," *Appl. Phys. Lett.* **55**, 2473-2475, 1989.
4. J.L. Jewell, A. Scherer, S.L. McCall, Y.H. Lee, S.J. Walker, J.P. Harbison, and L.T. Florez, "Low Threshold Electrically Pumped Surface Emitting Microlasers," *Electron. Lett.* **23**, 1123-1124, 1989.
5. Y.H. Lee, J.L. Jewell, A. Scherer, S.L. McCall, J.P. Harbison, and L.T. Florez, "Room-temperature Continuous Wave Vertical Cavity Single Quantum Well Microlaser Diodes," *Electron. Lett.* **25**, 1377-1378, 1989.
6. A. Scherer, J.L. Jewell, Y.H. Lee, J.P. Harbison, and L.T. Florez, "Fabrication of Microlasers and Micro-resonator Optical Switches," *Appl. Phys. Lett.* **55**, 2724, 1989.
7. D.A.B. Miller, "Optics for Low-energy Communication Inside Digital Processor: Quantum Detectors, Sources, and Modulators as Efficient Impedance Converters," *Opt. Lett.* **14**, 146-148, 1989.
8. A. Yariv, "Scaling Laws and Minimum Threshold Currents for Quantum-confined Semiconductor Laser," *Appl. Phys. Lett.* **53**, 1033-1035, 1988.
9. J. Jahns and A. Huang, "Planar integration of free-space optical components," *Appl. Opt.* **28**, 1602, 1989.