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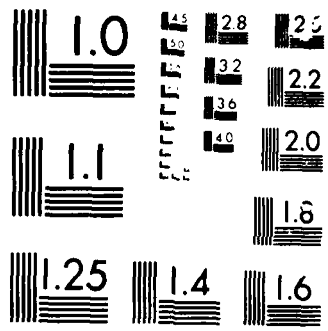
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High Power Semiconductor Laser Sources

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SURFACE EMITTING LASERS

Surface emitting injection lasers have been the subject of intensive research in the last years. Their potential advantages include:

1. a two dimensional laser array could be monolithically fabricated;
2. this laser can be integrated monolithically with other optoelectronic devices;
3. the laser output is expected to have a narrow beam divergence.

However, in order to fabricate a surface emitting laser, some design considerations should be properly addressed. The main problem resides in the fact that the length of the cavity is considerably shorter than that of conventional injection lasers. In the past several attempts to overcome this problem have been made, including the reduction of the cavity loss by an increase in the mirror reflectivity,[1,2] or an increase in cavity length by the use of a transverse junction injection.[3] The last approach was successfully combined with a multilayered, quarter wavelength reflector,[4] thus producing a vertical distributed feedback reflector laser.[5]

In spite of all these efforts, surface emitting lasers are still hard to operate, and they suffer from high threshold current density and low conversion efficiency.

The possibility to enlarge the vertical cavity by a transverse junction injection is very attractive, but we realize that by this approach, the p-n junction is a homostructure, and the threshold current density could be reduced further by one order of magnitude or more if we incorporate a double heterostructure into this design. This can be implemented by injecting carriers into several layers by interrelated electrodes as shown in Figure 1. Here, the current flows from the p-type GaAlAs to the n-type through the several layers of GaAs, producing a multiple active layer in a vertical stack, in between the several active layers to improve the reflectivity of the structure.

The implementation of the desired structure requires the following steps:

Growth of n-i-p-i-n-i... structure: This structure will constitute the multiple layer of the vertical laser, and can have a total thickness of ~20 μm. This multi-layer is grown by molecular beam epitaxy, which has the advantage of GaAs active layers that could be replaced, in the future, by quantum well double heterostructures. Subsequently, etching of a pattern in the lateral dimension and fill up of the etched sides with an n-type and a p-type GaAlAs, for the lateral electrodes and the lateral optical confinement.

This step requires mastery of the techniques for reproducible etch and two liquid phase epitaxy regrowths.

Metallization for the contact electrodes: Defining the high-reflecting mirrors for the vertical cavity. Having overcome steps 1 and 2, we are now in the process of fabricating a preliminary version of our lasers: we intend first to operate a laser in the regular geometry (with the cavity longitudinal dimension parallel to the layers) but with several active layers, one on top of the other, pumped with interrelated electrodes. By doing that, we hope that the main original idea will be demonstrated in an almost conventional laser, and the technological ground for the improved surface emitting lasers is laid down.

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UNSTABLE RESONATOR SEMICONDUCTOR LASERS

Unstable resonator semiconductor lasers have recently been the subject of research, owing to their potential for high power CW emission into a stable, narrow beam. Their potential advantages include:

1. efficient utilization of the lasing volume in a broad area device, resulting in low optical intensity at the mirror with high overall output power;
2. a narrow, potentially diffraction-limited output beam;
3. completely monolithic fabrication compatible with integration with other optoelectronic devices;
4. simplified processing, using relatively common photolithographic processes and requiring no cleaving to form end mirrors.

An unstable resonator semiconductor laser is fabricated upon a standard double heterostructure that is grown on a GaAs substrate by any of several methods, which include liquid phase epitaxy (LPE) and molecular beam epitaxy (MBE). In contrast to the usual Fabry-Perot laser, which possesses planar mirrors fabricated by cleaving, an unstable resonator laser is bounded by one or more curved mirrors (Figure 2a). The modes of such a resonator fill the entire lasing volume and can be highly selective for the fundamental lateral mode and thus can yield a narrow, single-lobed far field. In addition, the demagnifying mirrors have a destabilizing effect upon regions of self-focusing known as filaments and thus extend regimes of linear operation to higher power levels than with conventional designs.

Successful operation of the unstable resonator relies on the presence of high-quality curved mirrors on the end facets. The mirrors must be of the desired curvature, perpendicular to the active region, and smooth to within a fraction of a wavelength (Figure 2b). Wet chemical etching techniques have been demonstrated [6,7] which meet the first two criteria. In addition, several unstable resonator geometries have already been successfully demonstrated (Figure 3).[8-11]

Implementation of the more advanced structures which exhibit the properties listed above requires developing mirror fabrication techniques that yield mirrors of the requisite smoothness along with tailoring the composition of the GaAs double heterostructures to etch in vertical planes. The steps required for meeting these ends are as follows:

1. improvement of photolithographic techniques, using high-resolution marks and exposurement equipment;
2. improvements in etching technique, determining optimal temperature and concentrations for wet chemical and reactive ion etching procedures;
3. characterization of etching process in materials.
4. developing material compositions compatible with the etchants.

Besides the immediate goals listed above, successful operation of an unstable resonator semiconductor laser will, because of the wide variety of geometries possible with curved mirrors, demonstrate the feasibility of tailoring the optical characteristics of a laser to meet specific system applications.

References:

1. H. Soda, Y. Motegi and K. Iga, IEEE J. Quantum Electron. QE-19, 1035 (1983).
2. K. Iga, S. Ishikawa, S. Ohkouchi and T. Nishimura, Appl. Phys. Lett. 45, 348 (1984).
3. H. Ito, N. Koniagata, H. Yamada and H. Inaba, Electron Lett. 20, 577 (1984).
4. M. Ogura, T. Hata, N. J. Kawai and T. Yao, Japan J. Appl. Phys. 22, L112 (1983).
5. M. Ogura, T. Hata and T. Yao, Japan J. Appl. Phys. 23, L154 (1984).
6. 6. J. Salzman, T. Venkatesan, S. Margalit and A. Yariv, paper #ThV3, presented at the Optical Society of America Meeting, San Diego, California October 29-November 1, 1984.
7. M. Wada, K. Hamada, T. Shibutani, H. Shimizu, M. Kume, K. Itoh, G. Kano and I. Teramoto, IEEE J. Quant. Elect., vol. QE-21, p. 658 (1985).
8. J. Salzman, R. Lang, M. Mittelstein and A. Yariv, Appl. Phys. Lett., vol. 46, p. 218 (1985).
9. J. Salzman, R. Lang, S. Margalit and A. Yariv, Appl. Phys. Lett., vol. 47, p. 9 (1985).
10. J. Salzman, R. Lang, T. Venkatesan, M. Mittelstein and A. Yariv, Appl. Phys. Lett., vol. 47, p. 445 (1985).
11. J. Salzman, R. Lang, A. Larsson and A. Yariv, "The confocal unstable resonator semiconductor laser," Opt. Lett., 1985 (to be published).

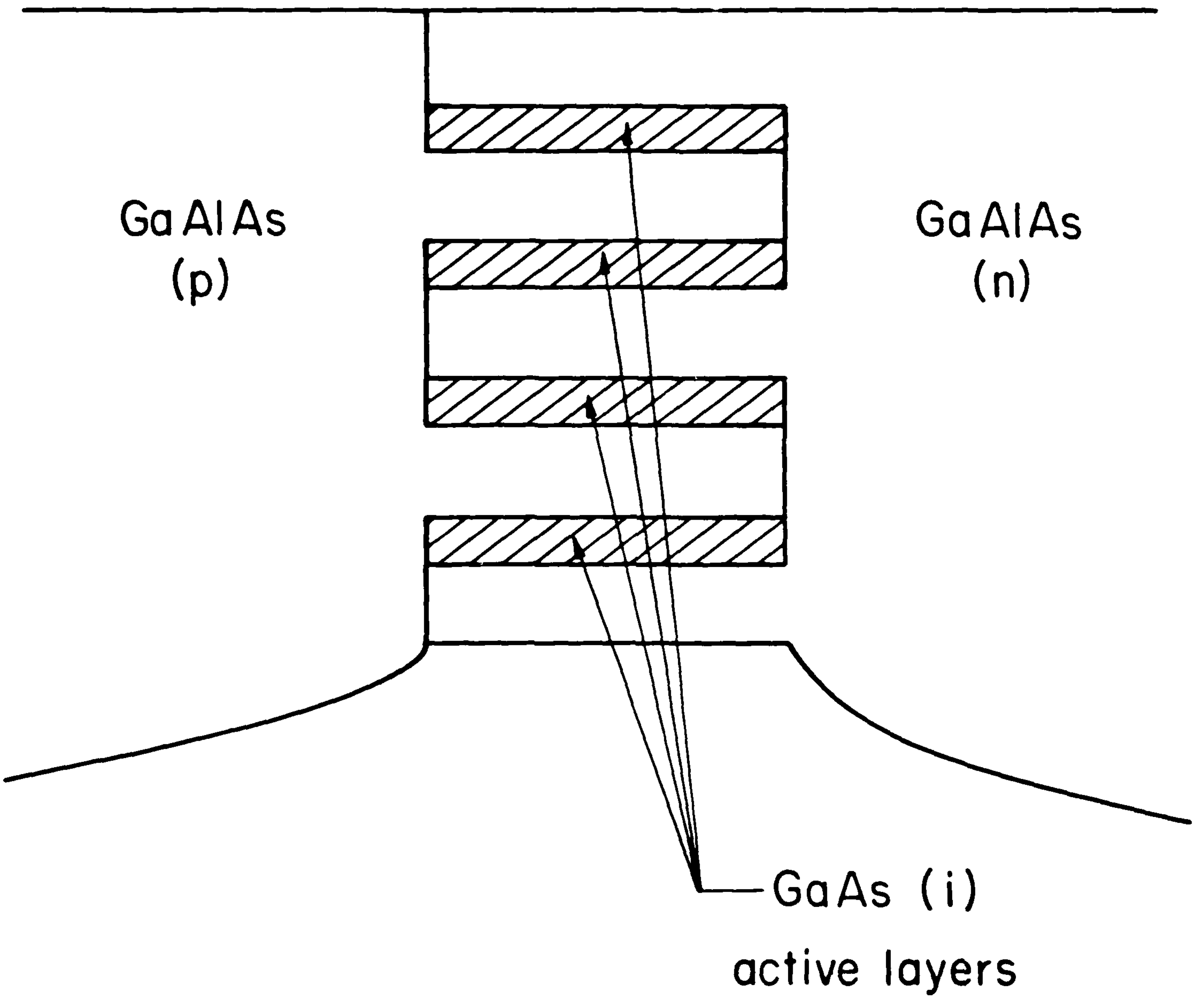
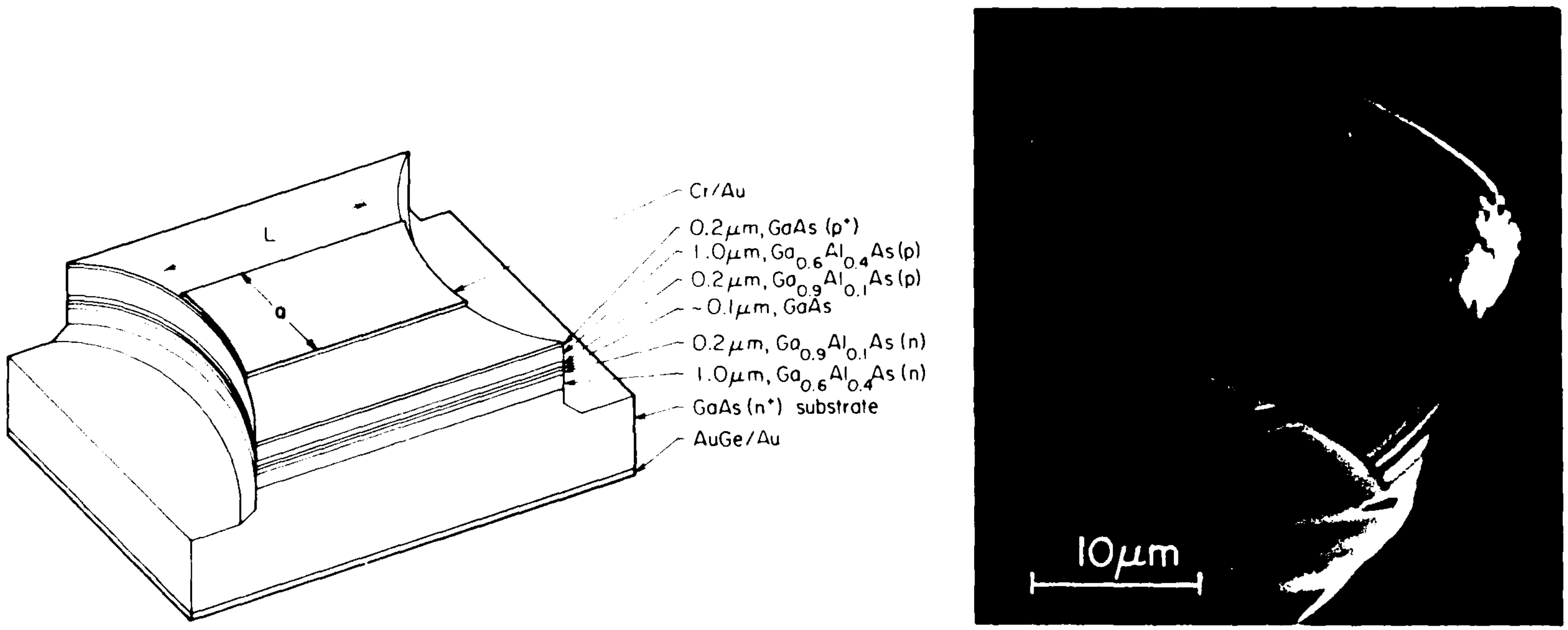


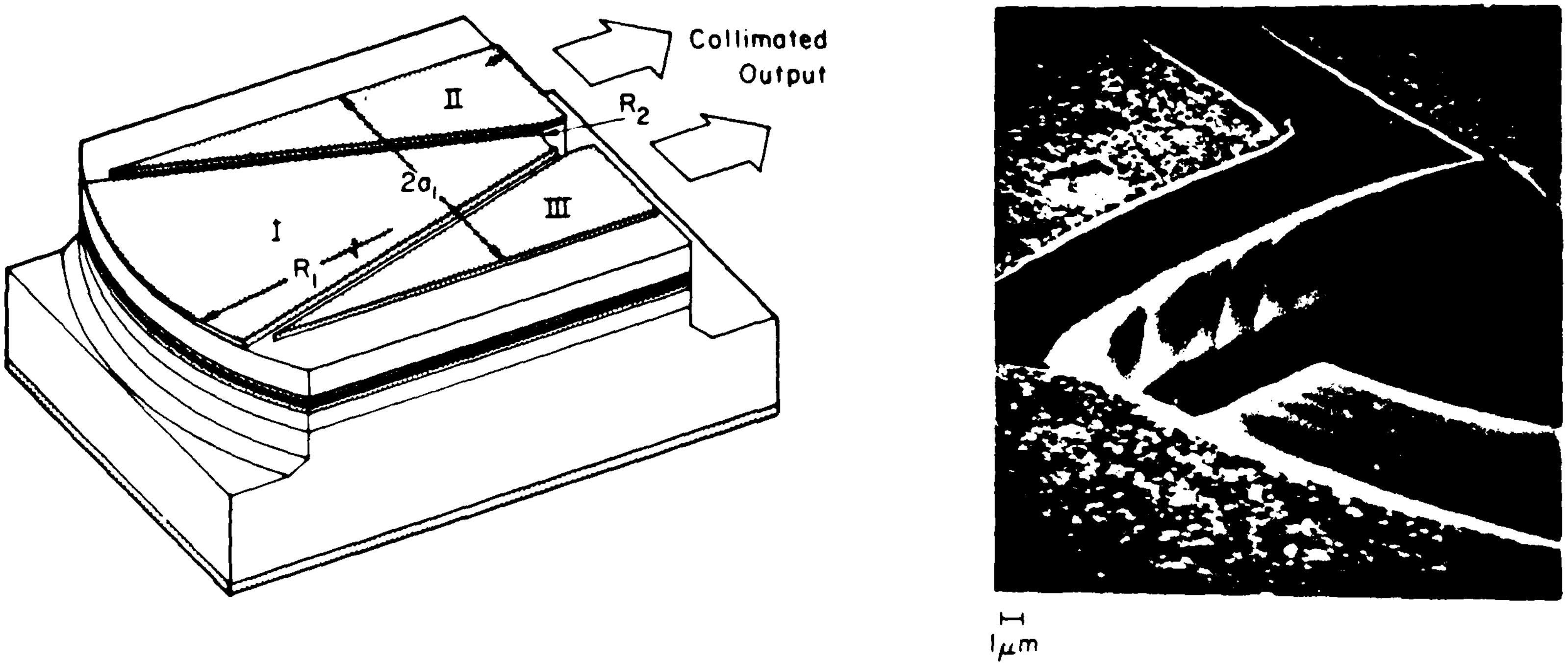
Figure 1


Cr/Au
0.2μm, GaAs (p⁺)
1.0μm, Ga0.6Al0.4As(p)
0.2μm, Ga0.9Al0.1As(p)
~0.1μm, GaAs
0.2μm, Ga0.9Al0.1As(n)
1.0μm, Ga0.6Al0.4As(n)
GaAs(n⁺) substrate
AuGe/Au
L
a
10μm

(a)

(b)

Figure 2



(a) (b)

Figure 3

ABSTRACTS OF PAPERS PUBLISHED DURING THIS REPORTING PERIOD

Efficiency of Unstable Resonator Semiconductor Lasers

J. Salzman, R. Lang, A. Yariv

The external quantum efficiency of η_d of an unstable resonator semiconductor laser is calculated in terms of the eigenvalue of the oscillating field. Design considerations for optimizing η_d by controlling the mirror reflectivities are given.

Frequency Selectivity in Laterally Coupled Semiconductor Laser Arrays

J. Salzman, R. Lang, A. Yariv

A longitudinal-mode analysis of a system of laterally coupled waveguided resonators is presented in the coupled-mode approximation. It is shown that variations in the mirror reflectivity of the individual channels result in coupling between the supermodes of the structure. This may lead to mode suppression by modulation of the threshold gain of different Fabry-Perot modes.

High Quality Molecular Beam Epitaxial Growth on Patterned GaAs Substrates

J. S. Smith, P. L. Derry, S. Margalit, A. Yariv

In this letter we describe a procedure for high quality molecular beam epitaxy (MBE) growth over finely patterned GaAs substrates which is suitable for device fabrication requiring lateral definition of small (~1-2μm) dimension. This method was used for the fabrication of index guided laser arrays. Yields of individual lasers exceeded 90%, and thresholds were uniform to 10%. Temperature and flux ratio dependence of faceting during MBE growth over patterned substrates is shown for temperatures ranging from 580 to 700°C and for As/Ga flux ratios from 1.4:1 to 4:1. The real index guided structure, which can be formed by a single MBE growth over a ridged substrate, is discussed. This technique should prove useful in the fabrication of devices which take advantage of unique features formed during regrowth by MBE.

Tailored-Gain Broad-Area Semiconductor Laser with Single-Lobed Diffraction-Limited Far-Field Pattern

C. Lindsey, P. Derry, A. Yariv

We demonstrate a 60μm-wide asymmetric tailored-gain broad-area semiconductor laser with a single-lobed diffraction-limited far-field pattern 2.5° wide. The method used to achieve gain tailoring may be used to create nearly arbitrary two-dimensional spatial gain distributions within a broad-area laser.

Fundamental Lateral Mode Oscillation via Gain Tailoring in Broad Area Semiconductor Lasers

C. Lindsey, P. Derry, A. Yariv

We show that by employing gain tailoring in a broad area semiconductor laser we achieve fundamental lateral mode operation with a diffraction-limited single-lobed far-field pattern. We demonstrate a tailored gain broad area laser 60μm wide which emits 450mW per mirror into a stable, single-lobed far-field pattern 3 1/2° wide at 5.3 I_{th}.

Tilted-Mirror Semiconductor Lasers

J. Salzman, R. Lang, S. Margalit, A. Yariv

Broad-area GaAs heterostructure lasers with a tilted mirror were demonstrated for the first time, with the tilted mirror fabricated by etching. These lasers operate in a smooth and stable single lateral mode with a high degree of spatial coherence. The suppression of filamentation manifests itself in a high degree of reproducibility in the near-field pattern.

Coherence and Focusing Properties of Unstable Resonator Semiconductor Lasers

M. Mittelstein, J. Salzman, T. Venkatesan, R. Lang, A. Yariv

The emission characteristics of unstable resonator semiconductor lasers were measured. The output of an 80μm-wide laser consists of a diverging beam with a virtual source 5μm wide located 50μm behind the laser facet. A high degree of spatial coherence of the laser output was measured, indicating single lateral mode operation for currents $I \leq 3\ I_{th}$.

Double Heterostructure Lasers With Facets Formed by a Hybrid Wet and Reactive-Ion-Etching Technique

J. Salzman, T. Venkatesan, S. Margalit, A. Yariv

Double Heterostructure Lasers were fabricated in which one of the laser facets was produced by a hybrid wet and reactive-ion-etching technique. This technique is suitable for GaAs/GaAlAs heterostructure lasers and utilizes the selectivity of the plasma in preferentially etching GaAs over GaAlAs. Lasers fabricated by this technique are compatible with optoelectronic integration and have threshold currents and quantum efficiency comparable to lasers with both mirrors formed by cleaving. The technique enables the use of relatively higher pressures of noncorrosive gases in the etch plasma resulting in smoother mirror surfaces and further eliminates the nonreproducibility inherent in the etching of GaAlAs layers.

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Surface Emitting Lasers, Unstable Semiconductor Lasers

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Unstable semiconductor lasers have been fabricated and their potential as high power laser sources has been analyzed.

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