AlGaAs lasers with micro-cleaved mirrors suitable for monolithic integration

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A technique has been developed for cleaving the mirrors of AlGaAs lasers without cleaving the substrate. Micro-cleaving involves cleaving a suspended heterostructure cantilever by ultrasonic vibrations. Lasers with microcleaved mirrors have threshold currents and quantum efficiencies identical to those of similar devices with conventionally cleaved mirrors.

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Recently, there has been substantial interest in the monolithic integration of semiconductor lasers with other optoelectronic devices.[1–3] The conventional method of obtaining optical feedback in a semiconductor laser is to cleave opposite facets of the substrate. This provides nearly perfect mirror surfaces, but is not compatible with many integrated optoelectronic circuits. If opposite cleaved facets of the substrate are used as mirrors, the number of optoelectronic devices that can be integrated onto the chip with the laser is severely restricted by the laser cavity length, which is typically about 300 μm.

Many techniques for fabricating lasers that do not rely upon opposite cleaved facets of the substrate for mirrors have been reported. Cleaved mirrors have been replaced by etched mirrors,[4] grown mirrors,[5] ion milled mirrors,[6] and distributed Bragg reflectors.[7] An alternate approach is to fabricate a curved laser cavity with mirrors on the same cleaved facet or on a cleaved corner.[8] For all of these approaches, the resulting lasers have generally been found to have significantly higher threshold currents and lower quantum efficiencies than lasers that have conventionally cleaved mirror.

In this letter we report on a new fabrication process in which laser mirrors are cleaved without cleaving the substrate. These lasers, which will be referred to as having micro-cleaved mirrors, have threshold currents and quantum efficiencies that are essentially identical to those of lasers that have conventionally cleaved mirrors. In addition, many electronic devices can easily be integrated onto the same chip for applications such as the integrated optical repeater.[3] These lasers can also be used in the integrated optoelectronic circuits that have been reported with lasers having etched mirrors.[1,2] Very short laser cavities, which have recently been reported using etched mirrors,[9] can also be fabricated with this new process.

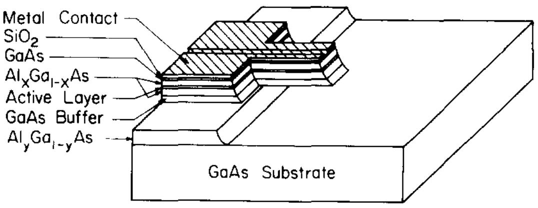

FIG. 1. Schematic diagram of a double heterostructure cantilever prior to mirco-cleaving.

The basic approach to obtain mirco-cleaved mirrors is to selectively etch underneath the double heterostructure, leaving a cantilever structure, as illustrated in Fig. 1. This cantilever can then be cleaved off by applying mechanical stress. This enables the fabrication of lasers with cleaved mirrors on a chip that has dimensions that are not restricted by the laser cavity length, as is shown in Fig. 2. The remaining area of the chip can then contain other optoelectronic devices.

The method used to fabricate the lasers reported in this letter was to grow the double heterostructure on top of a layer of $Al_yGa_{1-y}As$ of high aluminum content and to subsequently selectively etch this layer. The etchant that was used to etch the $Al_yGa_{1-y}As$ layer was concentrated HCl. Concentrated HCl at room temperature will etch the $Al_yGa_{1-y}As$ layer without significantly attacking the other AlGaAs layers. For $y = 0.8$ the etch rate was approximately 1.5 μm/min. To obtain the structure shown in Fig. 1, 25-μm-wide channels were first etched down to the $Al_yGa_{1-y}As$ layer using a nonselective etch $H_2SO_4H_2O_2:H_2O$ (1:8:8). This layer was then selectively etched in HCl until the double heterostructure was undercut by 20–25 μm. Next 1:8:8 was used to form a series of 20-μm-wide cantilevers from the overhanging double heterostructure. Figure 3 shows a scanning electron micrograph of a cantilever prior to micro-cleaving. The cantilevers were then cleaved using ultrasonic vibrations. Figure 4 is a scanning electron micrograph of a micro-cleaved mirror. Micro-cleavages were typically observed to have minute terraces (< 100 Å), but these terraces did not significantly affect the performance of lasers.

We have fabricated oxide stripe lasers with 7-μm-wide stripes that have micro-cleaved mirrors. For 150-μm laser

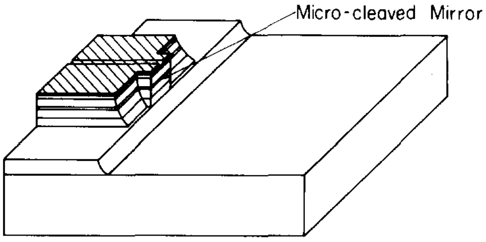

FIG. 2. Schematic diagram of a laser with a micro-cleaved mirror.

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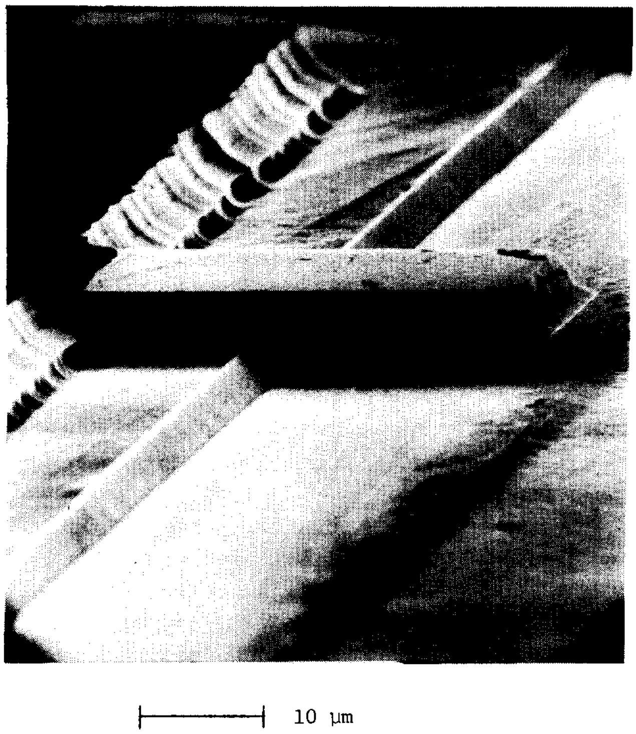

FIG. 3. Scanning electron micrograph of a double heterostructure cantilever prior to micro-cleaving.

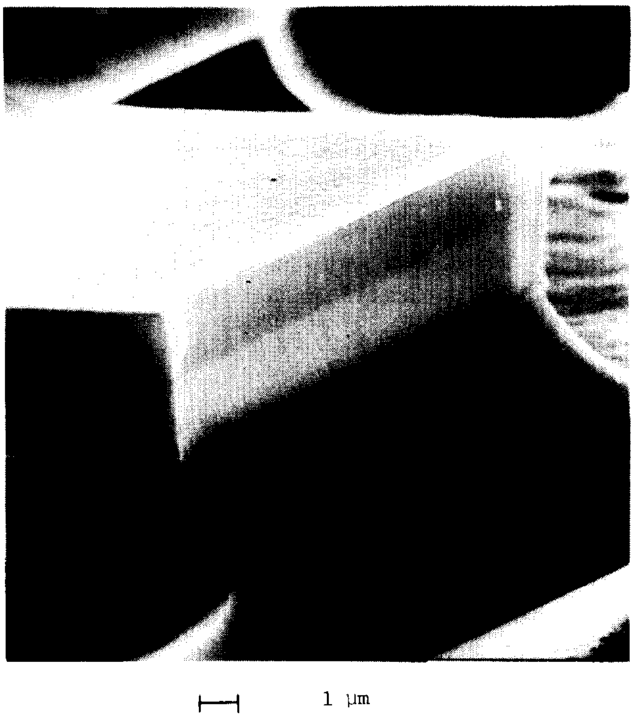

FIG. 4. Scanning electron micrograph of a micro-cleaved mirror.

cavity lengths, threshold currents for devices with either two micro-cleaved mirrors or one micro-cleaved and one conventionally cleaved mirror were 80–120 mA, and differential quantum efficiencies were 15–20% per facet. Results obtained for lasers having micro-cleaved mirrors were no different from the results obtained for lasers of identical structure having conventionally cleaved mirrors.

After being subjected to ultrasonic vibrations, approximately 50% of the cantilevers cleaved properly. The main reason for the failure of some of the cantilevers to cleave satisfactorily can be attributed to irregularities in the undercut edge. When the edge of an undercut was parallel to the cleavage plane, the cantilevers almost always cleaved properly.

It is also possible to form double heterostructure cantilevers without growing a AlGaAs layer of high aluminum content. In this case the double heterostructure is undercut by selectively etching the GaAs substrate with H_2O_2:NaOH ($pH = 7$). Initial experiments of cleaving devices show promising results.

We believe micro-cleaved mirrors can be fabricated for other laser structures such as buried heterostructure and transverse junction stripe lasers which have been fabricated on semi-insulating substrates. Low threshold lasers, such as these, are of particular interest for monolithic integration applications in which the chips have to be mounted substrate down.

In conclusion, a technique for cleaving laser mirrors without cleaving the substrate has been developed. Oxide stripe lasers with micro-cleaved mirrors have been fabricated which have threshold currents and quantum efficiencies comparable to oxide stripe lasers with conventionally cleaved mirrors. Lasers with micro-cleaved mirrors are well suited for integration with other optoelectronic devices. The process should be applicable to the fabrication of micro-cleaved mirrors on other laser structures and to the fabrication of lasers with very short cavity lengths. Finally, the technique of micro-cleaving is well suited to batch processing since ultrasonic vibrations can simultaneously cleave all of the laser mirrors on a wafer.

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[1] J. L. Merz, R. A. Logan, and A. M. Sergent, IEEE J. Quantum. Electron. **QE-15**, 72 (1979).
[2] T. Ota and T. Kobayashi, Jpn. J. Appl. Phys. **16**, 1253 (1977).
[3] M. Yust, N. Bar-Chaim, S. H. Izadpanah, S. Margalit, I. Ury, D. Wilt, and A. Yariv, Appl. Phys. Lett. **35**, 795 (1979).
[4] J. L. Merz and R. A. Logan, J. Appl. Phys. **47**, 3503 (1976).
[5] F. A. Blum, K. L. Lawley, and W. C. Holton, J. Appl. Phys. **46**, 2605 (1975).
[6] Y. Suematsu, M. Yamada, and K. Hayashi, Proc. IEEE **63**, 208 (1975).
[7] W. Ng, H. W. Yen, A. Katzir, I. Samid, and A. Yariv, Appl. Phys. Lett. **29**, 684 (1976).
[8] I. Ury, S. Margalit, N. Bar-Chaim, M. Yust, D. Wilt, and A. Yariv, Appl. Phys. Lett. **36**, 629 (1980).
[9] K. Inga, M. A. Pollack, B. I. Miller, and R. J. Martin, IEEE J. Quantum Electron. **QE-16**, 1044 (1980).