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1.3-μm InGaAlAs-BH laser with Cl_2/N_2 ECR plasma etched mesas

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Abstract: We developed a dry etching process suitable for fabricating InGaAlAs laser mesa stripes. We used optimized Cl_2/N_2 ECR plasma for etching an InGaAlAs laser multilayer structure. This Cl_2/N_2 ECR plasma led to a uniform etching rate and an anisotropic profile using a nitrified side-protection mechanism. This smooth and anisotropic dry etching produced a well-matched interface for semi-insulated Fe-InP regrowth. It also enabled successfully fabricating an InGaAlAs buried heterostructure laser. The laser showed stable operation at 85°C and long-term reliability over 5000 hrs.

Keywords: InGaAlAs, laser, Cl_2, N_2, ECR, dry etching

Classification: Photonics devices, circuits, and systems

References

[1] C. E. Zah, R. Bhat, B. N. Pathak, F. Favire, W. Lin, M. C. Wang, N. C. Andreadakis, D. M. Hwang, M. A. Koza, T. P. Lee, Z. Wang, D. Darby, D. Flanders, and J. J. Hsieh, "High-performance uncooled 1.3 μm $Al_xGa_yIn_{1-x-y}As/InP$ strained-layer quantum well lasers for subscriber loop application," *IEEE J. Quantum Electron.*, vol. 30, pp. 511–522, 1994.

[2] Y. Kawamura, A. Wakatsuki, Y. Noguchi, and H. Iwamura, "InGaAs/InGaAlAs MQW lasers with InGaAsP guiding layers grown by gas source molecular beam epitaxy," *IEEE Photon. Technol. Lett.*, vol. 3, no. 11, pp. 960–962, 1991.

[3] P. J. A. Thijs, T. van Dongen, J. J. M. Binsma, and E. J. Jansen, "High performance buried heterostructure 1.5 μm InGaAs/AlGaInAs strained-layer quantum well lasers diodes," *Proc. Indium Phosphide and Related Materials*, pp. 765–768, 1996.

[4] T. Tanbun-Ek, S. N. G. Chu, P. W. Wisk, R. Pawelek, A. M. Sergent, J. Minch, E. Young, and S. L. Chuang., "High performance buried heterostructure 1.55 μm wavelength AlGaInAs/InP multiple quantum well lasers grown entirely by MOVPE technique," *Proc. Indium Phosphide and Related Materials*, pp. 702–705, 1998.

[5] T. Takemasa, M. Kubota, T. Munakata, and H. Wada, "1.3-μm AlGaInAs buried-heterostructure lasers," *IEEE Photon. Technol. Lett.*, vol. 11, no. 8, pp. 949–951, 1999.

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Published July 10, 2004

[6] M. Aoki, T. Sudo, T. Tsuchiya, D. Takemoto, and S. Tsuji, "Advantage of InGaAlAs-MQW for high-temperature/high-speed operation of 1.3-μm DFB laser," *Proc. European Conference on Optical Communication*, vol. 1, pp. 123–124, 2000.
[7] T. Ishikawa, T. Higashi, T. Uchida, T. Fujii, T. Yamamoto, H. Shoji, and M. Kobayashi, "Evaluation of differential gain of 1.3 μm AlGaInAs/InP strained MQW lasers," *Proc. Indium Phosphide and Related Materials*, ThP-55, pp. 729–732, 1998.
[8] T. Okuda, H. Ko, Y. Ohsawa, K. Tsuruoka, T. Terakado, K. Kurihara, A. Gomyo, T. Nakamura, and K. Kobayashi, "Low-threshold 1.3-μm AlGaInAs buried heterostructure laser diodes for 85°C 10-Gb/s operation," *Proc. Optical Fiber Communication*, ThF5, pp. 420–421, 2002.
[9] T. Nakamura, Y. Ohsawa, T. Okuda, K. Tsuruoka, K. Kurihara, T. Terakado, T. Koui, and K. Kobayashi, "High-Quality 1.3-μm AlGaInAs MQW by Narrow-Stripe Selective Metalorganic Vapor-Phased Epitaxy and Its Application in Buried Heterostructure Laser Diodes," *Proc. Indium Phosphide and Related Materials*, A1-5, pp. 35–38, 2003.
[10] H. Sato, H. Uchiyama, K. Shinoda, T. Tsuchiya, A. Taike, K. Nakahara, and S. Tsuji, "Highly reliable InGaAlAs buried-heterostructure laser for 10-Gbit/s Ethernet," *Proc. European Conference on Optical Communication*, vol. 2, Lasers 5.3.4, 2002.
[11] H. Uchiyama, K. Shinoda, H. Sato, A. Taike, T. Taniguchi, and S. Tsuji, "Smooth and anisotropic dry etching of InGaAlAs using Cl_2/N_2 ECR plasma," *Proc. Indium Phosphide and Related Materials*, ThP-20, pp. 468–471, 2003.
[12] K. Shinoda, A. Taike, H. Sato, and H. Uchiyama, "Optimizing HBr-Br_2-H_2O etchants to form low defect regrowth interfaces for highly reliable InGaAsP/InP buried-heterostructure lasers," *J. Electrochem. Soc.*, vol. 150, no. 2, pp. G117–G121, 2003.

1 Introduction

Directly modulated uncooled 1.3-μm semiconductor lasers are key devices in low-cost 10-Gbit/s Ethernet lasers and access networks. An InGaAlAs multiple quantum well (MQW) laser [1-9] enables large differential gain and stable operation at high temperature, but aluminum-containing materials are difficult to use for device processing. Therefore Nakamura et al carried out a study on fabricating AlGaInAs MQW buried heterostructure lasers using a narrow-stripe selective metal organic vapor-phase epitaxy (MOVPE) without an oxidation of aluminum-containing MQW layers [9]. However, another method utilizing mesa structure fabrication has an easily controllable property for a current block. But the etching of the InGaAlAs layer structure for the mesa stripe fabrication is especially difficult because an aluminum-oxide layer, which functions as an etch-stop layer, rapidly forms on the etched surface. Moreover, buried heterostructure (BH) lasers require a smooth and controllable interface for semi-insulated InP regrowth by MOVPE. Thus, the mesa etching process for BH lasers should create a smooth and anisotropic surface. We have developed a smooth and anisotropic dry etching that uses Cl_2/N_2 ECR plasma and have used it to fabricate an InGaAlAs-BH laser

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that successfully operates stably at 85°C [10-11].

2 Experimental

The samples we used were (100) n-InP and InGaAlAs laser multilayer structures grown by MOVPE. The multilayer structure was composed of an InGaAlAs-MQW active layer, a p-InP cladding layer, and a p^+-InGaAs contact layer. We used SiO_2 stripes, made by thermal chemical vapor deposition and C_2F_6/CHF_3 reactive ion etching, as etching masks. We used an ANELVA ECR-6001 dry etching system with a Cl_2/N_2 gas mixture. After the surface was cleaned and a plasma-damaged layer was removed with an optimized HBr-Br_2-H_2O wet etchant [12], the dry etched InGaAlAs-BH laser mesa samples were buried with a semi-insulated Fe-InP layer using MOVPE. After the wafer process, the devices were cleaved to cavity lengths of 200 μm and 300 μm, and their front and rear facets were coated with high-refractive (40% and 90%) films. We used a scanning electron microscope (SEM) to observe the etched profiles and step differences. We also investigated some characteristics of the InAlGaAs-BH laser devices fabricated with our dry etching.

3 Results and Discussion

Figure 1 shows the etching rates of GaAs and InP as a function of the percentage of N_2 in the gas flow. The etching rate decreased as the N_2 percentage was increased. There was no difference in the rate between the GaAs and InP when the percentage was more than 25%. This means that the Cl_2/N_2 ECR plasma does not create steps in the sidewalls of multi-layered structures, such as an InGaAlAs laser structure. Figure 1 also shows the selectivity of SiO_2 masks to GaAs and InP as a function of the N_2 percentage. The values ranged from 5 to 59. The etching rate of InP and the selectivity of SiO_2 masks are thus sufficient for fabricating InGaAlAs laser mesa stripes. The SEM profiles of etched InGaAlAs laser structure samples for several N_2 percentages are in the margin of Fig. 1. Smooth and anisotropic etching was achieved when the percentage exceeded 25%. The N_2 apparently improves the anisotropy because a nitrified etch-stop layer, acting as a side-etch-protection film, forms on the sidewall. However, deep grooves that might be disadvantageous for Fe-InP regrowth of BH laser fabrication were formed along the mesa stripes when it exceeded 50%. Thus, we considered that the optimal N_2 percentage for laser mesa stripe etching was between 25% and 37.5%. A cross-sectional SEM image of the InGaAlAs-BH laser we fabricated using the optimized Cl_2/N_2 ECR etching is shown in Fig. 2. No voids were observed on the interface of the semi-insulated Fe-InP regrown layer. The smooth and anisotropic dry etching process achieved a satisfactory interface for the Fe-InP regrowth.

Figure 3-(a) shows typical light-current characteristics of our 200-μm-long InGaAlAs-BH laser measured at 25°C and 85°C. The threshold current (I_{th}) was 8 mA at 25°C and 18 mA at 85°C, which corresponds to a high characteristic temperature (T_0) of 74 K. The slope efficiency was 0.26 W/A at

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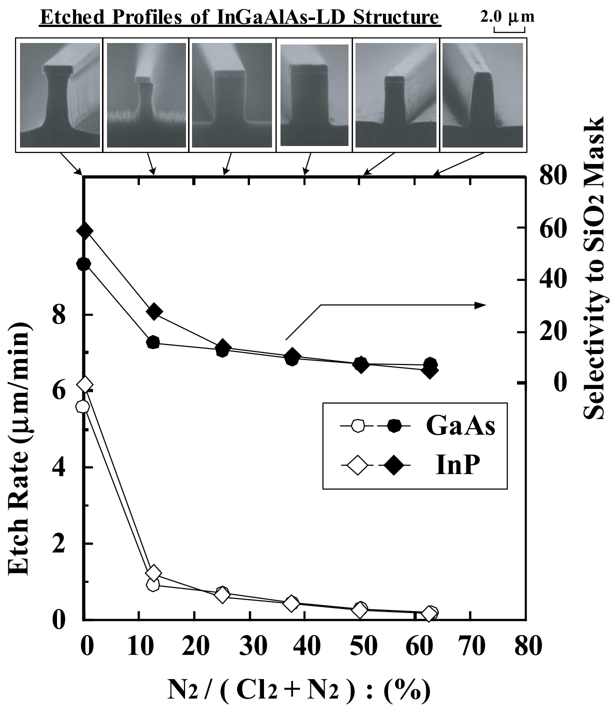

Fig. 1. Etch rates of GaAs and InP, and their selectivity to SiO_2 masks as a function of N_2 percentage in the gas flow.

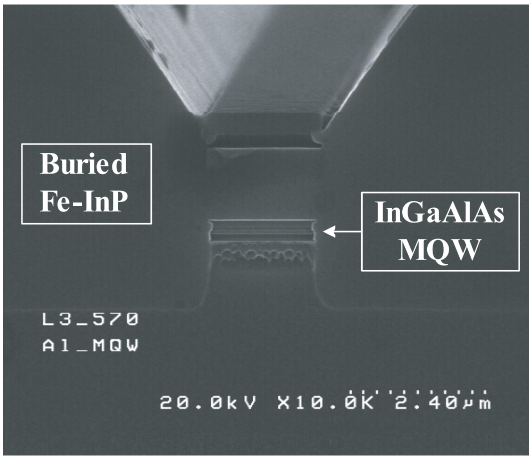

Fig. 2. The cross-sectional SEM image of the InGaAlAs buried heterostructure laser we fabricated.

25°C and 0.20 W/A at 85°C. The degradation in slope efficiency ($\Delta\eta$) between 25°C and 85°C was −1.1 dB. The InGaAlAs-BH laser had a relaxation oscillation frequency (f_r) of more than 12 GHz in the temperature range of 25 - 85°C, as shown in Fig. 3-(b). A schematic diagram of our InGaAlAs-BH laser device is also depicted in Fig. 3-(b). No significant degradation appeared after 5000 hrs in a lifetime test for a 300-μm-long device under automatic power control (APC) at 85°C with an output power of 10 mW. Thus, we demonstrated that our smooth and anisotropic dry etching process was suitable for fabricating InGaAlAs-BH lasers.

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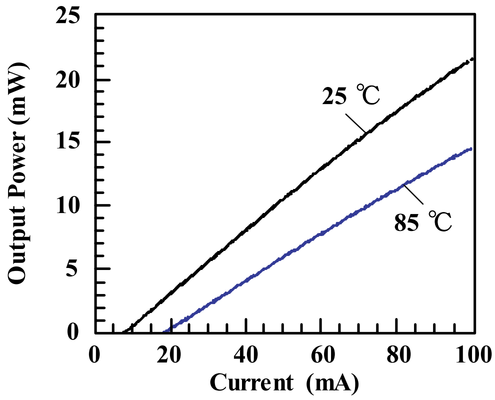
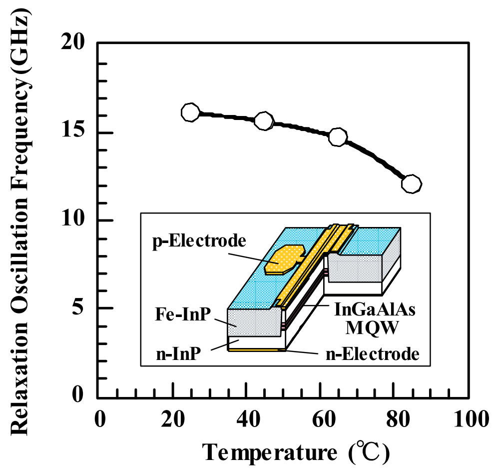


(a) Light-current characteristics of our InGaAlAs BH laser (200 μm-long device) at 25°C and 85°C.



(b) Temperature dependence on relaxation oscillation frequency and schematic diagram of our InGaAlAs-BH laser device.

Fig. 3.

4 Conclusion

We developed smooth and anisotropic dry etching that uses optimized Cl_2/N_2 ECR plasma and that is suitable for fabricating InGaAlAs-BH laser mesas. The plasma made no step on the sidewalls because of its uniform etch rate. Mixed N_2 gas plasma formed a nitrified etch-stop layer, which enabled the anisotropic etching, on the sidewalls. Thus, a smooth and anisotropic etched surface produces a satisfactory MOCVD regrowth interface, enabling an InGaAlAs-BH laser to operate reliably at 85°C.

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