Integration of High-Power Semiconductor Lasers Using Dry-Etched Mirrors

Peter Unger
Department of Optoelectronics, University of Ulm
89069 Ulm, Germany, peter.unger@e-technik.uni-ulm.de

Abstract

Broad-area InGaAs-AlGaAs laser diodes emitting at a wavelength of 980 nm with dry-etched mirror facets are presented. The devices exhibit optical output powers up to 1.5 W per facet at room temperature under continuous-wave operation. The results are comparable to lasers with cleaved facets made of the same epitaxial material. A chip has been fabricated, where several laser diodes and monitor photodiodes are monolithically integrated.

Introduction

Semiconductor laser diodes are well established mass products for optical data storage and optical communication applications. In the conventional fabrication process, the wafer is cleaved into bars to create the resonator mirrors of the lasers. These mirrors are then coated with dielectric layers to avoid corrosion of the facets and to modify the mirror reflectivities. The devices are tested on bar level and then cleaved into individual chip. This rather sophisticated production process prevents the price from dropping below 1 US-Dollar per device.

A fabrication process is discussed where the mirrors are produced by a dry-etching process. This technology has three main advantages. First, the production of the laser devices is easier and cheaper, because facet coating and device testing can be performed on the uncleaved wafer [1]. Second, the monolithic integration of lasers and other devices is possible [2]. And third, laser diodes with extended functionality can be realized since orientation and shape of the mirrors are not restricted to crystal planes [3].

Fabrication

Figure 1 schematically shows the process sequence for laser fabrication, where a dry-etching process for the laser mirrors is implemented which uses chemically-assisted ion-beam etching (CAIBE). In this process, the substrate surface is exposed to an argon ion beam and simultaneously to a gas flow of molecular chlorine. The etching behavior is dominated by two mechanisms, the physical

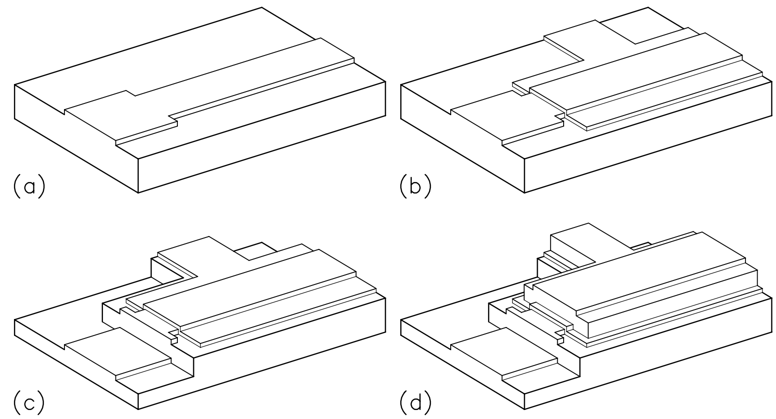

Figure 1: Fabrication process of lasers with dry-etched mirrors: (a) wet chemical etching of the ridge and deposition of the Si_3N_4 passivation, (b) evaporation of the p-contact metalization, (c) dry etching of the mirror using RIBE, and (d) deposition of galvanic heat spreader.

etching portion (sputter etching) caused by the ion beam and the chemical portion from the reactive gas. By adjusting ion-beam current density, ion-beam energy, chlorine gas flow, substrate temperature, and tilt angle of the substrate towards the ion beam, the process can be optimized with regard to etch rates, etching profiles and mirror surface roughness. Additionally, the quality of the etching mask has a strong influence on the roughness and orientation of the facet. In this study, a trilevel resist system is used, providing a thick resist mask with excellent lateral accuracy, very low sidewall roughness, and high etching resistivity.

The SEM micrograph at the top of Fig. 2 shows such a chip with 4 broad-area lasers and the integrated photodiodes. The light-emitting facets are orientated to the front of the chip. The two central lasers have an area of $1000\,\mu\text{m} \cdot 100\,\mu\text{m}$, the length of the two outer lasers is $500\,\mu\text{m}$. To avoid reflection back into the lasers, the facets of the photodiodes are slanted. On the right and left sides of the chip, bond pads with an area of $200\,\mu\text{m} \cdot 200\,\mu\text{m}$ are located. Since the p contact is used as plating base for the galvanic deposition of the heat spreading layer, the contact layout provides electrical connections between all devices on the wafer during fabrication. These interconnects can be seen at the left and right hand side of laser chip.

Characterization

Figure 3 shows the continuous-wave characteristics of a single broad area device which has been mounted junction-side down on a diamond heat sink. At an operating current of 4 A, an output power per facet of 1.5 W has been achieved for a $1000\,\mu\text{m} \cdot 100\,\mu\text{m}$ broad area laser with uncoated dry-etched facets. The

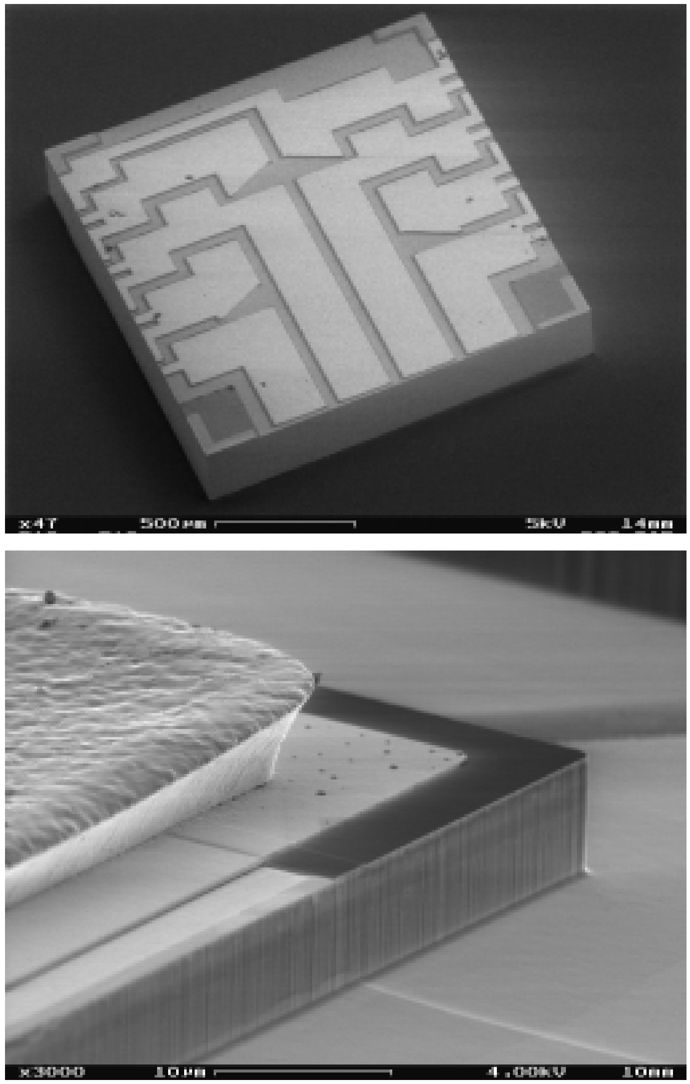

Figure 2: The SEM micrograph at the top shows an integrated optoelectronic laser chip with dry-etched facets. The chip consists of 4 monitor photodiodes and 2 pairs of lasers with cavity lengths of 500 μm and 1000 μm. The micrograph at the bottom provides a detailed view of the dry-etched laser facet. On the top of the structure the electroplated gold heat spreader is clearly visible.

I-*V* characteristic shows a kink voltage of 1.3 V and a differential resistance of 0.109 Ω. The wall-plug efficiency which has been calculated by dividing the optical output power of both facets by the product of operating current and voltage drop features a maximum value of 54 % at a current of 1.2 A.

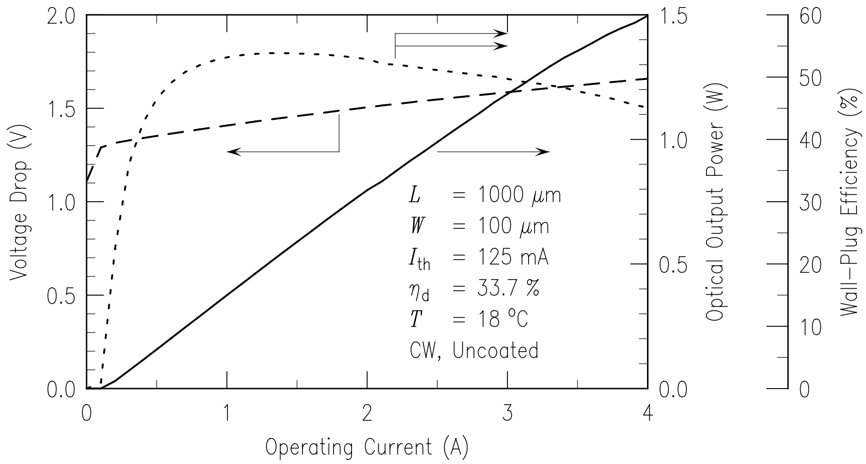

Figure 3: Continuous operation of a junction-side-down mounted broad area laser with uncoated dry-etched facets having a cavity length of $L = 1000\,\mu$m and a lateral width of $W = 100\,\mu$m. Shown are the output power per facet (solid line), the I-V characteristic (dashed line) and the wall-plug efficiency (dotted line) of the device.

Outlook

To improve the spatial beam quality of high-power lasers, unstable resonators can be implemented by etching mirrors with laterally-curved shapes. In these resonators, the lateral mode profile is determined by the mirror shape. Compared to conventional single-mode lasers having a lateral waveguide, the optical power density in the cavity is significantly reduced leading to reduced spatial hole burning and therefore less filamentation. Since also the optical power density on the mirror facets is reduced, less device failures due to catastrophic optical mirror damages (COMD) should be observed.

Acknowledgments

This article is based on contributions from Franz Eberhard, Eckard Deichsel, and Roland Jäger currently working toward their Ph.D. theses at the University of Ulm. The research project has been funded by the German Federal Ministry of Education, Science, Research, and Technology (BMBF) under contract 16 SV 530 / 7.

[1] P. Vettiger et al., IEEE J. Quantum Electron. **27**(6), 1319–1331 (1991).
[2] P. Unger et al., Microelectron. Eng. **23**, 461–464 (1994).
[3] P. Unger et al, J. Vac. Sci. Technol. B **11**(6), 2514–2518 (1993).