Surface features of the AlN optical coating deposited on the facet of a high-power AlGaAs/GaAs semiconductor laser

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Abstract. The facets of high-power AlGaAs/GaAs semiconductor lasers were coated with thin dielectric AlN films using reactive ion-plasma technique. The refractive indices of the films were measured by the ellipsometry. It is shown the technique makes it possible to obtain AlN films with a refractive index close to that of a single-crystal material. The scanning probe microscopy was used to estimate the surface roughness of the films. The comparative results of the aging tests of lasers based on the same laser heterostructure with SiO₂ and AlN coatings on their facets are presented.

1. Introduction

Reliability and lifetime are among the most important aspects in the production of semiconductor lasers. This is especially important for high-power semiconductor lasers of the infrared range. Such devices must work effectively under conditions of light generation with high power density, and at the same time should have sufficient lifetime for practical applications. In the case of lasers with Fabry-Perot resonators, it is also necessary to achieve an optimal reflectance of the facets to ensure the most efficient light output. This is achieved by applying thin antireflection coatings on the mirrors. Transparent oxide Al₂O₃ and SiO₂ films are often used for these purposes.

At the same time, near-IR lasers grown in the AlGaAs/GaAs material system with a high aluminum content (> 20%), suffer from the catastrophic optical mirror degradation (COMD). It is known, that aluminum on the cleaved surface of the heterostructure is oxidized upon contact with atmospheric oxygen [1], and, as a result, it leads to an output mirror burn and a laser failure [2]. Thus, the use of Al₂O₃ and SiO₂ coatings becomes ineffective, since oxygen from the film can migrate to the active region of the laser and cause oxidation without direct contact with the atmosphere.

AlN, due to its properties, can resolve the issue. This material has high mechanical strength, chemical and thermal resistance, which is important when the laser operates at high output power, as well as it has suitable optical properties. At the same time, a high-quality film does not contain oxygen [3], which prevents oxidation of the active region and at the same time provides the required reflectivity of the output mirror. That is, it simultaneously acts as an antireflection and a passivating coating.

The purpose of this work is to estimate the surface quality of AlN coatings deposited on the output facet of the AlGaAs/GaAs laser and on GaAs (100) substrates, in order to compare the efficiency of AlN and SiO₂-coated lasers.
2. Experiment and Results

AlN coatings were fabricated in the triode-type reactor by the reactive ion-plasma sputtering of pure aluminum in an extremely pure nitrogen plasma at a working gas pressure of \(\sim 3.5 \times 10^{-3} \) Torr. Before the deposition process, the chamber was preliminarily pumped out to the pressure down to \(9.0 \times 10^{-7} \) Torr. Then an aluminum target was etched in argon plasma to remove surface oxide. The samples also were processed with short-term soft argon etching for the same purpose.

Coatings were deposited simultaneously on GaAs (100) reference substrates and on the facets of AlGaAs/GaAs laser heterostructures (35% Al content) grown by MOCVD and emitting at a wavelength of 820 nm. (figure 1). During the process, the coating thickness was estimated by the interferometry technique based on the expected refractive index value with the use of a source laser with a wavelength of 450 nm. After the extraction of samples, thickness and refractive index of the coatings were measured using ellipsometry. Thickness measurements were also performed using SEM. The thickness of the coatings was \(d=65–200 \) nm, the refractive index was \(n=1.73–2.22\). For 820 nm Fabry-Perot stripe lasers with an aperture width of 100 \(\mu\)m, the aim was to obtain a reflection coefficient of 3.5% for the output mirror. In this case, typical values for coatings were: \(d\sim85 \) nm, \(n\sim2.05\). The surface topography of the laser mirrors was obtained using the Bruker Dimension Icon AFM (figure 2).

As can be seen in the images, the AlN film repeats the relief of the heterostructure, in particular, the individual layers can be distinguished and their thicknesses match up with the structure design. In addition, there is a certain relief of wavelike lines passing across the entire surface, and a step at the interface between the region of heavily doped AlGaAs and the Si-doped GaAs buffer layer. We believe that this relief arises when the heterostructure is mechanically cleaved into laser chips because of the
presence of mechanical stresses in the structure associated with strong doping. Nevertheless, despite the presence of obvious relief, the amplitude of the local surface roughness of the active region of the laser is small and rarely amounts even a few nanometers (figure 3).

We have previously shown [4] that the roughness of the AlN film grown by our technology on the “epi-ready” GaAs (100) substrates can vary from a few to more than a dozen nanometers and, apparently, depends on the quality of the growing film. Coatings with a more pronounced relief have a higher refractive index, which indicates that the AlN film grown has a higher crystal quality. Thus, the surface roughness of several nanometers may be neglected in laser applications and the optical quality of the coating can be considered satisfactory.

To estimate the effectiveness of the use of AlN as a passivation coating, comparative aging tests were carried out. The tests were carried out for lasers with an aperture width of 100 μm and facets coated with SiO₂ and AlN. The heterostructure from which the lasers were fabricated was MOCVD grown on a GaAs (100) substrate.

![Figure 3. Texture, waviness and surface roughness in the selected sections (figure 2): a) cut 1, d=18 nm; b) cut 2, d=88 nm; d - cut width](image_url)

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![Figure 4. Aging test of SiO₂ and AlN coated lasers 100 μm x 2 mm at RT.](image_url)

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The results of aging tests and the light-current characteristics are presented in figure 4 and figure 5. As can be seen from the figures, AlGaAs laser with a high aluminum content and SiO₂ antireflection coating shows a sharp drop in output power and fails completely in less than 2 hours. Its maximum output power is less than 1 W at a pump current of ~ 1.5 A. At the same time, an AlN-coated laser
provides a maximum output power of up to 5 W at a pump current of ~5 A. A slight (~10 %) deterioration of output power after 200 h is observed.

![Figure 5. L-I characteristics of AlGaAs lasers, λ = 820 nm](image)

3. Conclusion
As a result, it can be concluded that high-quality optical coatings based on aluminum nitride grown in an oxygen-free atmosphere are a promising replacement for the widely used oxide coatings. This is of current interest for AlGaAs lasers with a high Al content, for which oxygen, when in contact with the waveguide region, will lead to early failure of the device. The coatings obtained by the method of reactive ion-plasma sputtering of aluminum in a pure nitrogen environment not only provide the reflectance, necessary for an efficient lasing, but also play the role of passivating coatings, protecting the waveguide region of lasers from oxidation. This makes it possible to increase a maximum output power and the device lifetime. At the same time, the technology of AlN coatings fabrication is rather simple and cheap. The wide range of attainable AlN refractive index allows one to obtain coatings with controlled parameters.

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