Optical Coatings for Disk Lasers

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The performances of disk lasers can be improved with optical coatings which is shown for two different applications. For an AlGaAs disk laser, the efficiency was increased from 34 % to 50 % using an antireflective coating. Additionally, such a coating passivates the surface resulting in an higher lifetime. For an AlGaN disk laser, the Bragg mirror was fabricated by dielectric layers to achieve the required high reflectivity over 0.995 with only 9 layer pairs and a thermal stability up to 800 °C.

1. Introduction

Thin layers of dielectric materials have a wide range of applications. Especially for optoelectronic devices, such coatings are needed to improve the performances. With optical coatings, the surface reflectivity can be adjusted resulting in higher efficiencies. But also the passivation effect increases the lifetime of such devices. The high quality of the deposited layers is an important factor mainly for high output power densities. The intension is to achieve coatings with low absorption by the use of stoichiometric oxides. A methode to get such layers is the reactive ion-beam sputter deposition [1]–[4], which was used in this work.

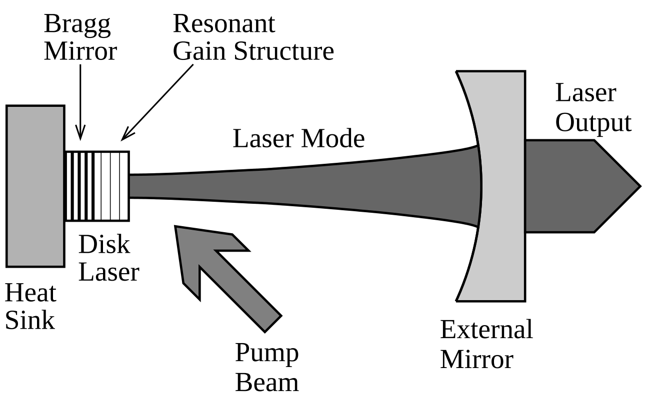

Fig. 1: Illustration of a disk-laser setup. The semiconductor disk laser itself is soldered on a heat sink and consists of a Bragg mirror and a resonant gain structure. An external concave mirror is used to build up the resonator. The pumping is performed optically by a laser beam.

In Fig. 1, a disk-laser setup, also known as OPSDL (*optically-pumped semiconductor disk laser*) or VECSEL (*vertical-external-cavity surface-emitting laser*) is shown [5]–[7]. The disk laser is pumped optically with e. g. an high-power laser bar or laser stack. The pump light is absorbed in the resonant gain structure where the generated carriers recombine and produces laser emission. The resonator is built up by the Bragg mirror and the external concave mirror. For a good thermal management, the disk laser is soldered on a heat sink. There are a lot of applications for optical coatings on such a disk-laser setup. The external mirror mostly has dielectric multilayer coatings to achieve the required high reflectivities with very low absorptions. But also bandpass filters are used for intra-cavity frequency doubling [8],[9]. Especially in the AlGaN material system, the Bragg mirror consists of dielectric layers due to the small refractive index change between AlGaN and GaN. The coating of the disk laser surface is also an important fact which influences the properties of the laser. In the next sections, two examples for applications of optical coatings on disk lasers will be presented.

2. Antireflective Coating on Disk-Laser Surface

An increase not only of the efficiency but also of the lifetime can be obtained by an AR (*antireflective*) coating. On a AlGaAs disk laser with an emission wavelength of 980 nm, a $\lambda/4$ thick Al_2O_3 layer with a refractive index of $n = 1.66$ was deposited on the surface.

In Fig. 2, the output characteristic of a disk laser is shown. In the left part of the graph, the optical output power is depicted over the whole pump power. It can be seen, that the slope in the characteristic of the coated disk laser and so the efficiency is larger compared to the disk laser without coating. The laser threshold decreases from 425 mW to 300 mW. One reason is the decrease in the surface reflectivity for the pump wavelength of 808 nm at a pump angle of 45° from 0.2 to 0.05. More pump light can reach the absorption region in the semiconductor material, the pumping is more efficient. This effect is taken into account in the right part of the graph. Here the output power is plotted over the absorbed pump power. The coated disk laser still shows a higher efficiency compared to the uncoated one. The differential efficiency η_{diff} increases with coating from 34 % to 50 %. Due to the decreased surface reflectivity for the laser wavelength of 980 nm from

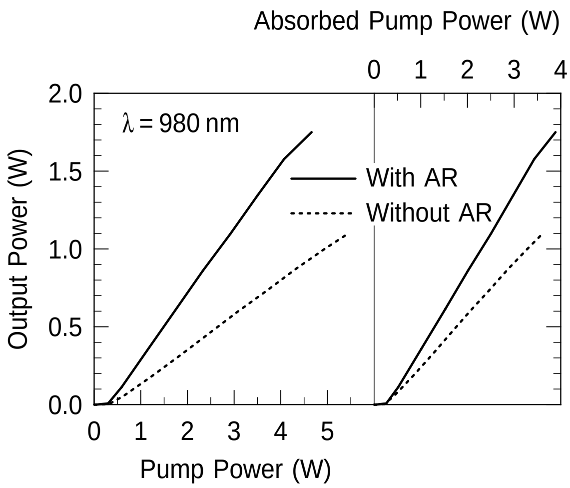

Fig. 2: Optical output power over pump power and absorbed pump power for a disk laser with and without AR coating.

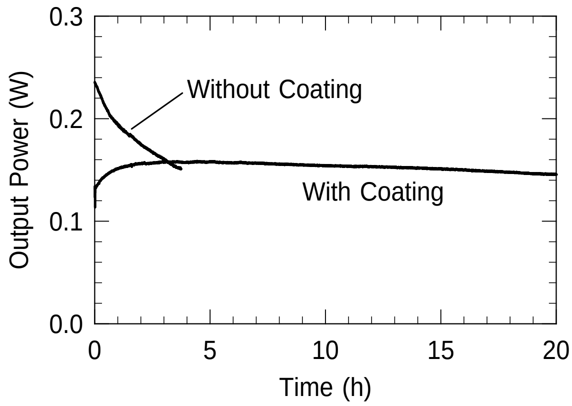

Fig. 3: Longtime measurement of the output power of a disk laser with and without AR coating.

0.3 to 0.02, the whole outcoupling reflectivity of external mirror plus surface reflectivity is lower and more light can be coupled out. The threshold pump power is not effected by this decrease from 0.986 to 0.98 and shows 290 mW in both cases. Also the maximum output power of the coated laser is larger due to the increased output transmission from 1.4 % to 2 %.

In Fig. 3 the influence of the passivation of the used AR-coating is shown. It can be seen, that the output power of the uncoated laser rapidly decreases in the first hours of operation. In contrast, the output power of the coated laser remains nearly constant over the time. This results show the improvement of the longtime stability of a disk laser by a passivation layer.

3. Bragg Reflector for AlGaN Disk Lasers

In the material system of AlGaN, an epitaxially grown Bragg reflector is not suitable due to the small refractive index contrast of GaN and AlN [10]. A better way is to use dielectric materials to achieve a high reflectivity with an adequate number of layers [11]–[13]. For such a disk laser with an emission wavelength of 405 nm and a pump wavelength of 355 nm at 40°, a Bragg reflector with SiO_2 and Ta_2O_5 was fabricated. For the characterization, some test substrates were coated during the deposition process.

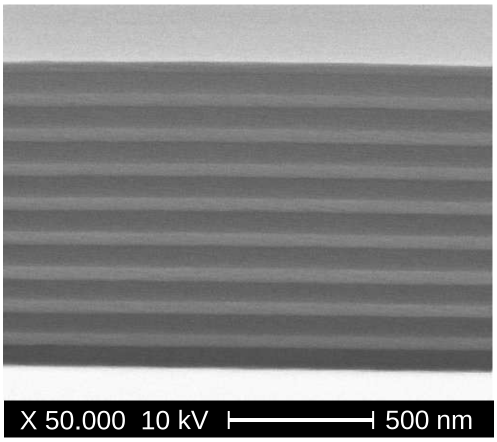

Fig. 4: SEM picture of the dielectric Bragg mirror. On a GaAs test substrate (white) 18 layers can be identified. Each layer pair consists of 67 nm SiO_2 (dark grey) and 45 nm Ta_2O_5 (bright grey).

An SEM picture of the deposited Bragg reflector can be seen in Fig. 4. On a GaAs substrate (white), 9 layer pairs can be recognized. The low-refractive material is SiO_2 with a thickness of 67 nm and appears as the darkgrey layers in the SEM picture. The brighter-grey layers are 45 nm thick Ta_2O_5 which is used as the high-refractive material. The whole thickness of the mirror is approx. 1 µm. In Fig. 5, the wavelength-dependent reflectivity for 0° is shown. There is a good agreement between the simulated and measured curves. For the emission wavelength of 405 nm the reflectivity shows the required maximum. Additionally, the simulated reflectivity for 40° is included in the diagram to recognize the maximum for the pump wavelength at 355 nm.

The reflectivity is dependent of the refractive indices of the substrate n_S, the incident medium n_0, the low n_L and high n_H refractive material, and the number of layer pairs m.

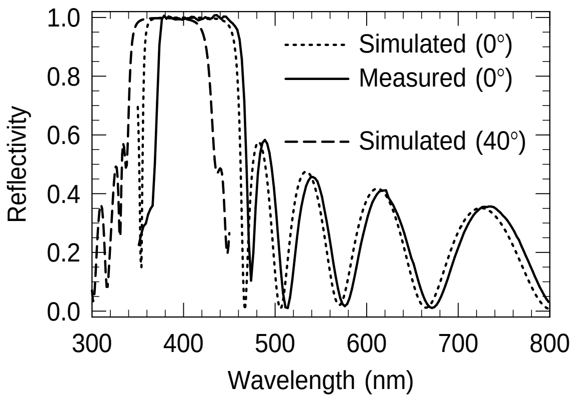

Fig. 5: Simulated and measured reflectivity over wavelength of the dielectric Bragg mirror containing 18 layers. The simulated curve for 355 nm and 40° is also given.

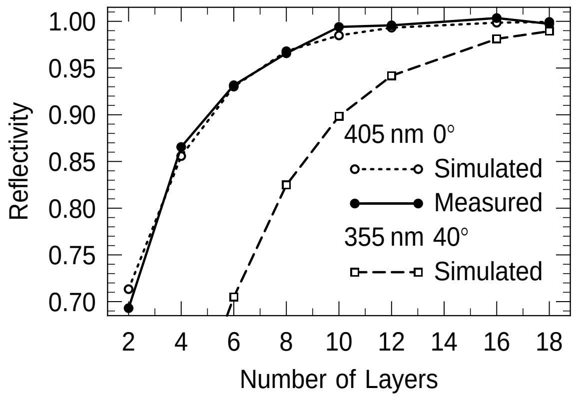

Fig. 6: Simulated and measured reflectivity for 405 nm and 0° versus the number of layers. The simulated curve for 355 nm and 40° is also given.

It can be calculated by using [14]

$$R = \left(\frac{1 - \frac{n_S}{n_0} \left(\frac{n_H}{n_L} \right)^{2m}}{1 + \frac{n_S}{n_0} \left(\frac{n_H}{n_L} \right)^{2m}} \right)^2 . \tag{1}$$

During the depostion sequence of the disk laser, different test substrates were removed between the deposition of the individual layer pairs. So it was possible to measure the reflectivity dependency on the number of deposited layers that is plotted in Fig. 6. There is a high agreement between the simulated reflectivity (Eqn. 1) for the emission wavelength of 405 nm at 0° and the measured one. With 18 layers, a reflectivity of over 0.995 is achieved. Additionally the simulated reflectivity for the pump wavelength of 355 nm at 40° is depicted. It can be seen that the reflectivity for 18 layers is 0.99 which is high enough for an effective pumping.

With an RTA process (*rapid thermal annealing*), the 18-layer Bragg mirror on a Si test substrate were stressed with different temperatures for 2 minutes under nitrogen atmosphere. After each temper step, the wavelength dependent reflectivity were measured as depicted in Fig. 7. There is only a small shift in wavelength and a small decrease in reflectivity.

In Fig. 8, the change of the reflectivity for 405 nm is drawn over the temper temperature like indicated by an arrow in Fig. 7. Up to a temperature of 800 °C, no significant change can be observed. A decrease in the reflectivity starts not below 900 °C. Also the wavelength shift of the band edge is given (right arrow in Fig. 7). Over the temperature range up to 1000 °C there is only a shift of 12 nm. These small changes of the Bragg mirror indicate the high stability of the coated dielectric layers. Therefore, such optical coatings are predestinated for the use with high optical power densities.

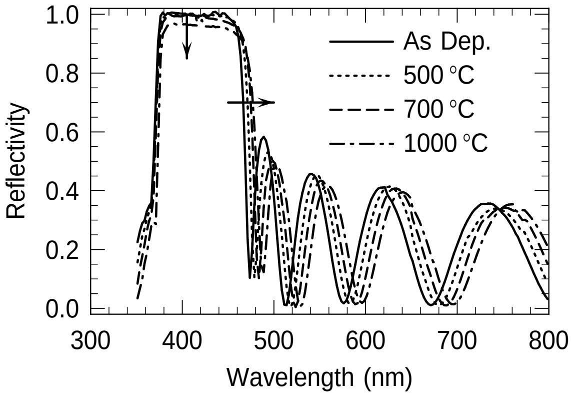

Fig. 7: Wavelength-dependent reflectivity for different temperatures.

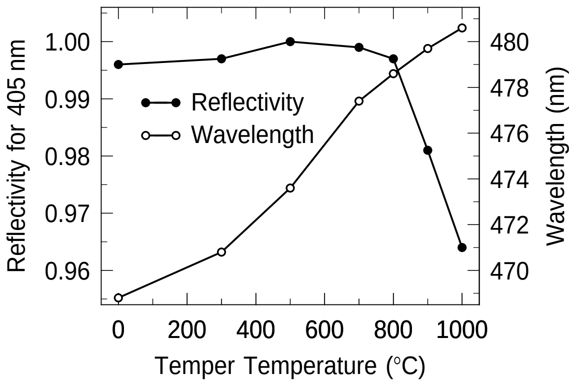

Fig. 8: Reflectivity for 405 nm and wavelength shift on band edge for different temperatures.

4. Conclusion

Optical coatings are an important component for the fabrication of disk lasers. With a simple $\lambda/4$-AR coating on the surface of a disk laser, the efficiency and lifetime were increased. For an AlGaN disk laser, the Bragg mirror was realized by dielectric layers. A reflectivity over 0.995 was achieved with 9 pairs. The mirror shows a thermal stability up to 800 °C.

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