Development and Technology of Surface Emitting Laser Diodes

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A novel technique for the realization of a surface emitting, single mode laser diodes is presented. The concept is based on a coupling process between the laser mode propagating in the active region and a surface mode on top of the laser diode. This technique provides both efficient surface emission with a low beam divergence as well as a single-mode-like emission from a conventional GaAs/AlGaAs double heterostructure laser diode. The emission spectra are explained by a model based on ray optics, which allows an optimization of this technique. The main advantage of this new type of laser diode is its simple fabrication, which requires no regrowth like is the case for single mode DBR and DFB laser diodes.

1. Introduction

Surface emitting semiconductor laser diodes have emerged as an important device in optoelectronic technologies such as optical recording, guided wave signal processing and high-speed-data transmission through fibers. The most important impact of laser diodes is the area of transmission systems for optical telecommunication. The performance of these systems has been pushed forward by the development of single longitudinal mode (SLM) laser diodes.

Therefore mode control in laser diodes has been a major field of investigations. Several SLM laser diode configurations have been realized so far. Among the various types of SLM laser diodes the distributed Bragg reflector (DBR) and the distributed feedback (DFB) laser seem most promising in terms of practical advantage [1].The DBR laser incorporates an external grating in the end section of the active waveguide, while the DFB laser incorporates the grating in the active waveguide.

Recently we have reported on novel surface emitting laser diodes, which are based on a surface mode emission (SME) technique [2], [3]. By coupling the laser mode to a surface mode we have achieved surface emission from conventional GaAs/AlGaAs laser diodes with a beam divergence of 0.2^{o}. In addition we have found that the SME process provides a mode selection process in the laser diode. Therefore the SME-technique has a high potential for the realization of a novel type of surface emitting SLM laser diode.

2. Technology

The laser diodes were grown by MOCVD. A cross section of the GaAs/AlGaAs double heterostructure laser diodes is shown in Fig. 1. The metal stripe on top (thickness 200 nm, width 50 µm) shows a 30 µm x 200 µm large window at a total laser length of 500 µm, where a surface is etched into the p-AlGaAs cladding layer with the grating grooves normal to the metal stripe. The surface grating is required for the coupling between the laser light and the surface mode. A 3rd-order grating (period 1300 nm, depth 100 nm) was produced by standard photolithography and a wet-chemical etching technique. The grating is coated with a 300 Å thick Au-film and polyimide as dielectric. The polyimide forms a waveguide structure on top of the laser diode and allows the existence of a transverse electric polarized TE_0-surface mode.

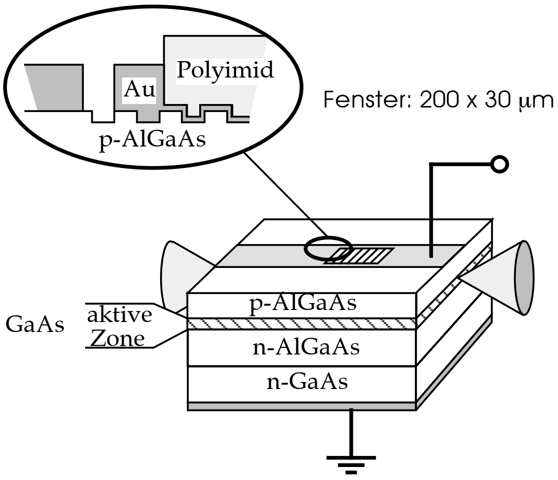

Fig. 1. Geometry of a surface emitting laser diode based on surface mode emission

3. Farfield Pattern

Locally in the window of the metal stripe the laser light propagating in the active region excites the TE_0-mode via 3 grating vectors (grating vector $k_g = 2\pi/\Lambda$) according to

$$k_{laser} - 3.k_g = k_{TE0} \qquad (1)$$

The TE0-mode decays radiatively and emits light due to the coupling condition

$$k_{TE0} - n.k_g = k_{light}.\sin\alpha_n \qquad (2)$$

The emission angles α_n are given by

$$\alpha_n = \sin^{-1}[n_{eff} - (3 + n)\lambda/\Lambda)] \qquad (3)$$

where n_{eff} is the effective mode index of refraction and n is the order of the grating. For the 3rd-order grating used in the present configuration three different emission angles are possible (n = 1, 2, 3).

The resulting farfield pattern of the laser diode measured in a full angular scan from -90° to +90° in the plane parallel to the laser stripe is shown in Fig. 2. For a laser emission wavelength of 879.17 nm the radiation pattern shows three emission peaks at $\alpha_1 = +42.1^o$, $\alpha_2 = -0.5^o$ and $\alpha_3 = -43^o$. The emission peaks are due to the radiative decay of the TE_0-mode excited by the laser light propagating from the left to the right mirror facet. The emission peaks of the laser light propagating in the opposite direction are of much less intensity due to the smaller gain length, which is a consequence of the asymmetric location of the surface emitting area relative to the mirror facets, as is indicated in Fig. 1.

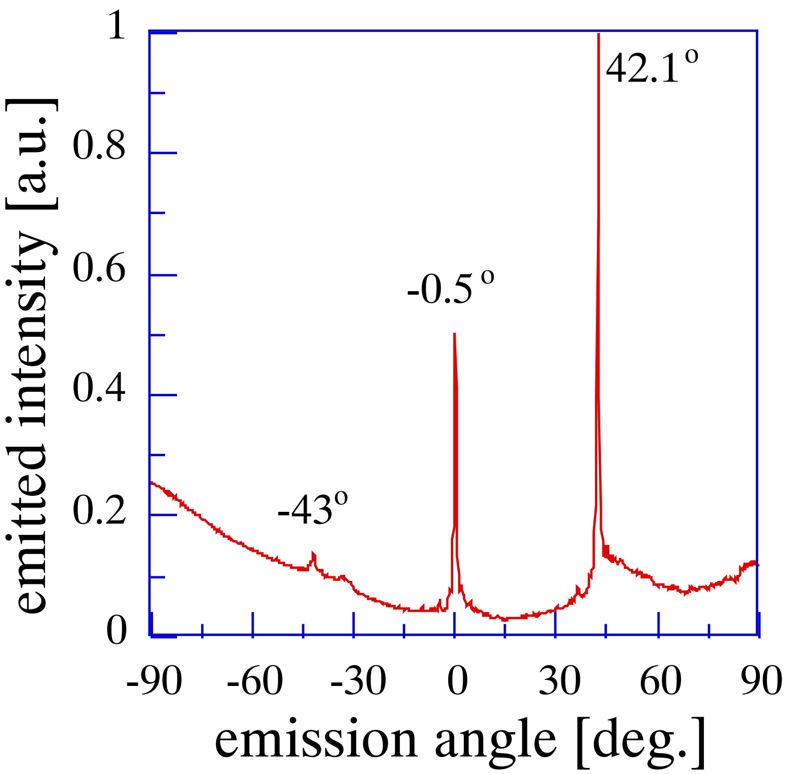

Fig. 2. Farfield pattern of a surface emitting SME laser diode

4. Wavelength Emission Spectra

In addition to the surface emission the SME technique provides a laser mode selection process. Therefore the SME technique has a high potential for the realization of a SLM laser diode.

In a conventional Fabry-Perot laser diode the longitudinal modes are spaced 2 - 10 Å apart, whereas the optical gain spreads over several hundred angstroms. Because the modal losses are primarily due to the mirror loss, which is independent of frequency and equal for all modes, the net gain difference between various longitudinal modes is very small. As a result many modes can reach lasing threshold, leading to multimode oscillations. To increase the gain difference between various modes, a frequency-dependent loss has to be introduced, while simultaneously a wavelength-selective mechanisms has to be added, that feeds back part of the light into the original cavity.

In case of the SME laser diode the strong interaction between the laser mode and the TE_0-surface mode in the waveguide is responsible for an additional wavelength selective feedback mechanism. The emission spectrum of a reference laser diode, which is not modified for surface mode emission, is shown in Fig. 3 (left). Due to the laser stripe width of 50 µm the longitudinal mode spectrum is smeared out by lateral modes. The completely different emission spectrum of a SME laser diode with a window length of 200 µm is shown in the right part of Fig. 3. The spectrum shows a main peak at 879 nm, and some small remaining single peaks. The main peak consists of two closely spaced lines, so the SME spectrum is still not a real single laser mode emission. This is due to the fact that the SME process in not yet optimized. However the high potential of the SME feedback process to achieve a real single mode operation is obvious.

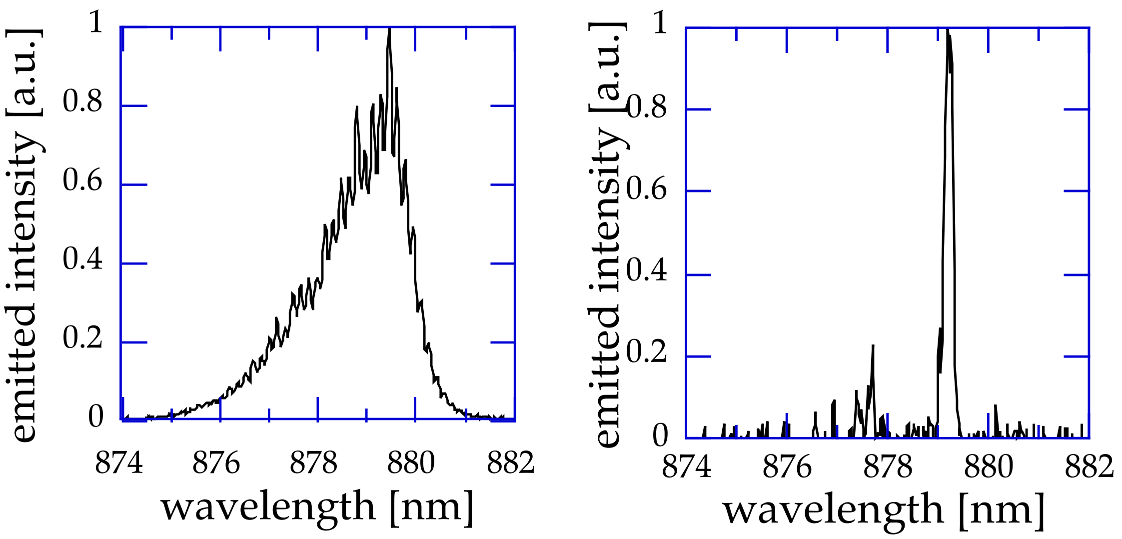

Fig. 3. Wavelength emission spectrum of the reference laser diode (left) and of the SME laser diode (right).

5. Discussion

The main advantage of the SME-type of laser diode as compared to surface emitting DBR- and DFB- single mode laser diodes is its simple fabrication process, because no regrowth is required. The SME process allows a free adjustment of the surface emission angle by a proper choice of the grating period. The emission wavelength is determined by parameters of the waveguide structure (i.e. the thickness and the refractive index of the dielectric waveguide), which are adjusted independent of the sample growth. This provides a high flexibility in processing laser diodes with desired emission characteristics, which is of high interest for many applications, like coupling in optical fibers or free-space optical interconnects.

The efficiency of the SME process depends strongly on the surface grating parameters and on the distance between the active region and the surface grating. The use of a 1-order grating increases the coupling efficiency, which results in enhanced surface emission and in a stronger mode selection process. This work is presently under progress.

References

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