GaAs/AlGaAs/InGaAs Bandgap Lasers — From DH Lasers to VCSELs

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Starting from the growth of double hetero (DH) semiconductor bandgap lasers, in the material system AlGaAs/GaAs we are now optimizing laser devices such as a twin waveguide laser and a laser interferometer based on vertical cavity surface emitting lasers (VCSEL).

1. MBE

MBE (molecular beam epitaxy) technique allows the epitaxial growth of different compounds. One of the model materials for optoelectronics are epitaxial layers of III-V semiconductors, mainly GaAs and related compounds. The controlled growth of single crystalline layers on an atomic scale makes it possible to design new materials with optimized electrical and optical characteristics. A solid source MBE system (MOD GEN II) is used for the growth of AlGaAs/GaAs semiconductor lasers and InGaAs quantum well lasers; thus, this machine is further equipped with an indium cell. As doping materials we use silicon for n-doping and carbon for p-doping.

2. Lasers

We started laser growth with double hetero (DH) GaAs/AlGaAs laser structures. This material was characterized by processing broad area lasers and measuring their electrical and optical properties. The threshold current density and differential efficiency are comparable to lasers processed from industrial grown materials [1].

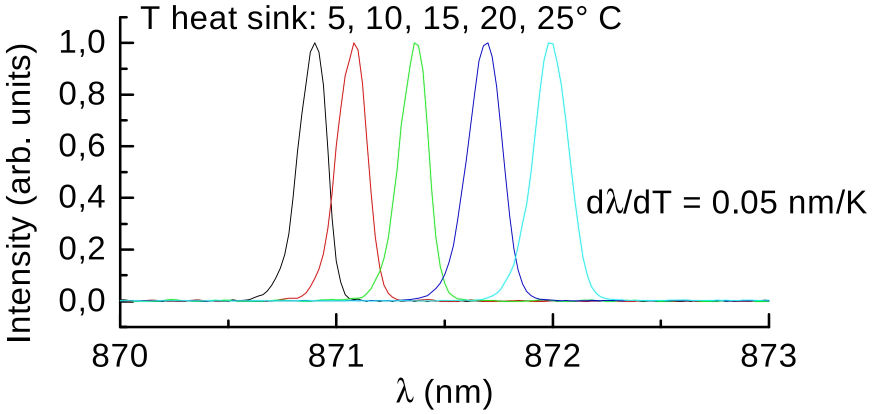

Fig. 1: Emission spectrum of dfb laser 4th order at different heat sink temperatures.

As a next step, ridge lasers were processed out of DH material. The ridge forms a lateral optical waveguide, which allows the realization of single mode lasers, where in addition a longitudinal mode control is needed. A simple model for calculating the lateral optical waveguide is the effective index model. The difference of the effective transverse refractive index and the width of the ridge determines how many lateral waveguide modes are possible and the divergence of the facet emission in lateral direction. Based on the ridge laser design we started to manufacture “single mode lasers” by incorporating a longitudinal mode control via a 4th order dfb (distributed feed back) grating. The reason for choosing a 4th order grating (period 515 nm) at this time was the established holographic grating definition with our HeCd laser setup for this grating period. The measured lasers showed a drift in the emission wavelength of about 0.05 nm/K, as can be seen in Fig. 1 (linewidth limited by the used spectrometer) due to change of the refractive index with temperature, which is in good agreement with literature [2].

As a next step, InGaAs SQW (single quantum well) lasers with separate confinement layers were grown. Strained InGaAs QWs show higher peak material gain than unstrained QWs or bulk material. The lattice mismatch between GaAs and InGaAs determines the so-called critical thickness for InGaAs layers on GaAs. Layers thinner than the critical thickness can be grown without relaxation effects. There are different models for calculating the critical thickness, e.g. by Matthews and Blakeslee or People and Bean [3]. One difficulty in the growth of strained InGaAs layers on GaAs is the calibration of In content and growth rate with RHEED (reflected high energy electron diffraction) measurements, originating from the lattice mismatch of the two materials. Additionally, optical problems remain in InGaAs QW lasers due to the large antiguiding effect and the nonlinear gain behavior at high current densities. E.g. the current density for narrow gain guided lasers increases dramatically for widths below 20 µm [3]. Therefore, a relatively strong index guiding is needed for narrow lasers. The grown SQW material was characterized with broad area lasers and showed threshold densities comparable to state of the art lasers [4], [5]. Ridge lasers with widths from 2 µm to 6 µm show kink-free light output (fig. 2) up to current densities of 5 times threshold density (limited by the setup) and the measured far field pattern indicates that only one lateral mode exists.

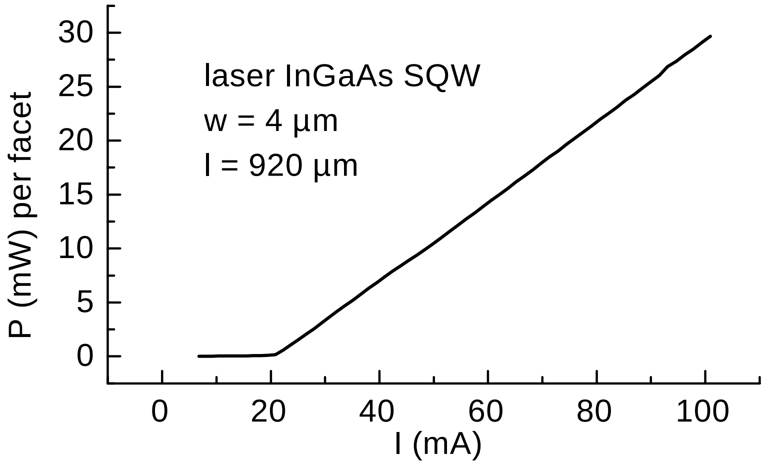

Fig. 2: Emitted power versus injected current of an InGaAs SQW laser (ridge width 4 µm).

Currently we are working on two laser projects, a twin waveguide laser and a laser interferometer.

2.1 Twin waveguide laser

The goal of this project is the realization of a grating coupled twin waveguide laser, where the two waveguides are the active laser waveguide and a passive waveguide formed by Au/SiO/SiN. The waveguide are coupled via a surface relief grating atop of the semiconductor (Fig. 3). These lasers allow postprocessing wavelength adjustment and high side mode suppression [6].

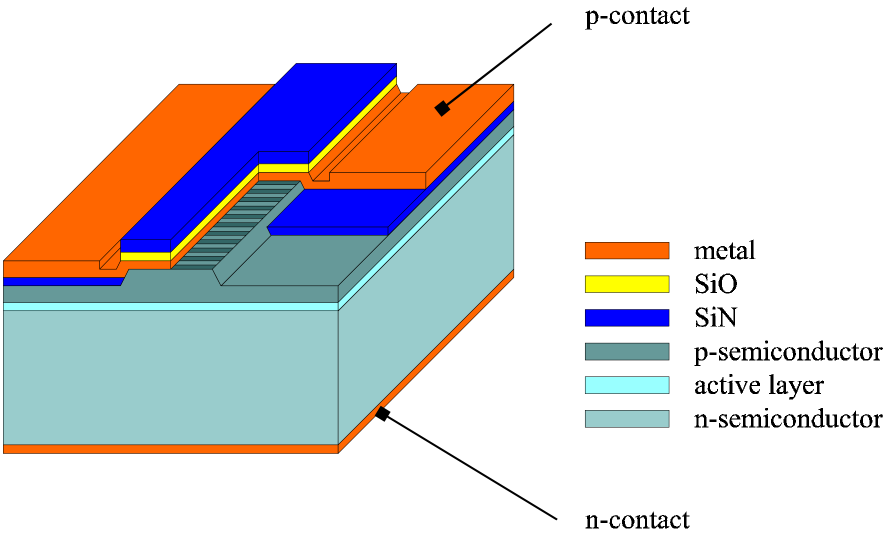

Fig. 3: Twin waveguide laser schematic.

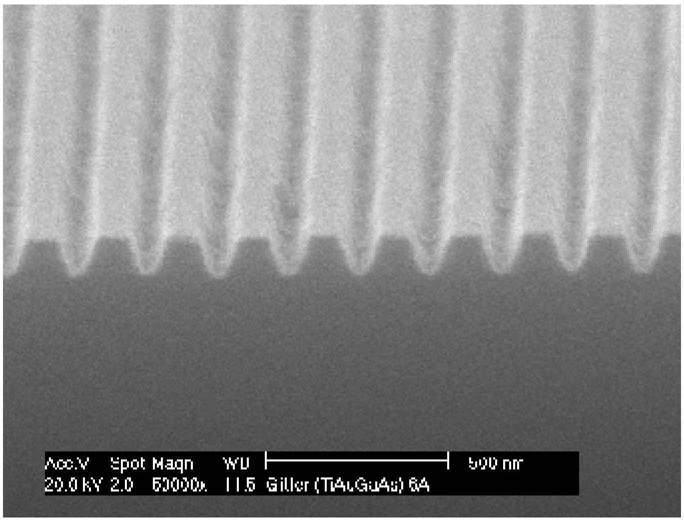

Fig. 4: SEM picture of 190 nm period grating etched into GaAs (photoresist removed)

The use of diluted photoresist (thickness 50 nm) allows us to produce grating periods as small as 180 nm holographically with a HeCd laser (lower limit for grating period:

325 nm/2 = 162.5 nm) in standard resist material. The used InGaAs QW laser material for the twin waveguide laser is designed for emission at about 980 nm, thus needing a grating period of about 190 nm, which is accessible with our setup as shown in Fig. 4.

2.2 Laser interferometer

The realization of a laser interferometer, consisting of a VCSEL and a detector integrated on one chip is the final goal of this project. At the beginning, Bragg mirrors consisting of GaAs and AlAs layers were grown and characterized by reflection measurement and layer thickness measured by scanning tunneling microscope (Fig. 5).

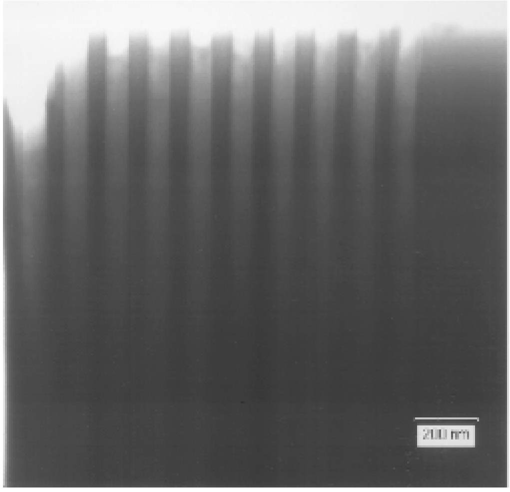

Fig. 5: STEM picture of AlAs/GaAs Bragg mirror.

The first VCSEL structures we realized consist of an upper dielectric Bragg mirror – made of SiO/SiN in a PECVD (plasma enhanced chemical vapor deposition) system – deposited on an MBE grown active region and a lower AlGaAs/AlAs Bragg mirror. These lasers showed single mode emission at room temperature but relatively broad linewidth [7]. Improvements are achieved by using a selective oxidation technique to reduce problems with current spreading and QWs as active region.

3. Conclusion

We started the growth of AlGaAs/GaAs bandgap lasers and were able to realize DH structure laser, strained InGaAs QW lasers and VCSELs which are state of the art, and in the near future we are going to realize new single mode lasers and an integrated laser interferometer.

References

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