GaAs/AlGaAs Based Intersubband and Interminiband Mid-Infrared Emitters

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Intraband optical transitions in the conduction band of GaAs/AlGaAs heterostructures are used to generate mid-infrared radiation. Bandstructure engineering and epitaxial growth techniques make it possible to tailor the emission wavelength of mid-IR light emitting diodes over a broad range (6 – 12 micrometer). We report on the realization of these emitters, showing two different concepts. The first, interminiband emitter is based on optical transitions across the minigap of a strong coupled superlattice. The second concept is using optical transitions between discrete states in a system of coupled quantum wells. Emission, photovoltage and transmission spectra are presented. Self consistent calculations of these structures are performed and compared to the experimental data. The structures are designed to achieve population inversion in different subbands of the conduction band.

1. Introduction

Environmental monitoring, medicine, and many other technological branches are yearning for compact light sources in Mid-Infrared (MIR) part of the spectrum. The only commercially available solid state lasers working in MIR are based on lead-salt semiconductors. Since the demonstration of the first Quantum Cascade Laser (QCL) by Faist et al (1994) [1] it became a viable source of coherent (MIR) radiation. A significant progress in the performance and operating characteristics of the QCLs has been achieved during the last five years. In 1996 operation above room temperature and peak powers of 100 mW [2], as well as CW operation at 110 K [3] was reported. A distributed feedback (single mode) QCL [4] and tunable QCL [5] were introduced in 1997. Microcylinder QCL with a bow-tie mode is reported in 1998 [6].

All these results have only been reported using a single material system, InGaAs/InAlAs lattice matched to InP. The strain requirements limit the composition of the InGaAs and the InAlAs ternaries. The GaAs/AlGaAs [7] system offers very good lattice match over the whole range of aluminum content in AlGaAs. Emitters based on this material are demonstrated [8] and lasing action at cryogenic conditions is achieved [9]. GaAs/ AlGaAs is the most common III-V semiconductor material system used in the technology. Economical aspects of its using are also not negligible, since many possible applications are cost limited which is the only obstacle in their introduction to praxis.

2. Unipolar Quantum Cascade Emitters

Radiation in common laser diodes is achieved via radiative recombination of electron-hole pairs across the bandgap. Quantum cascade emitters are using optical transitions of electrons between the discrete states within the conduction band of a semiconductor heterostructure. Thus the emitted wavelength is significantly less temperature dependent compared to the bandgap emitter. Bandstructure engineering allows tailoring of the emission wavelength to the application requirements over a broad range.

A Quantum Cascade (QC) emitter consists of an active cell, where the radiative transitions take place, and of an injector. The injector supplies electrons into the upper state of the active cell and secure extraction from its lower states. Active cell-injector units are cascaded (typically 25 units in cascade).

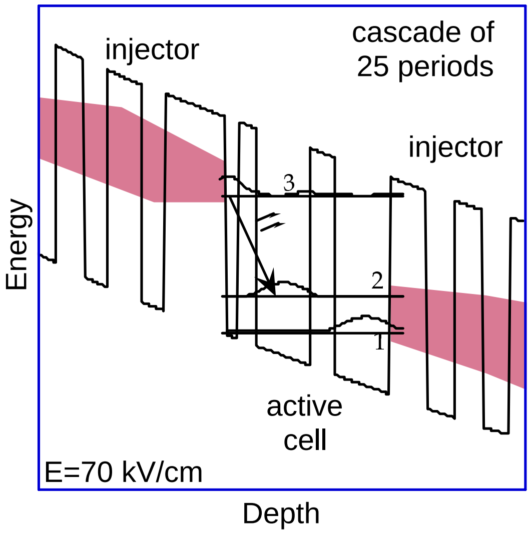

Fig. 1: Conduction band of the intersubband emitter

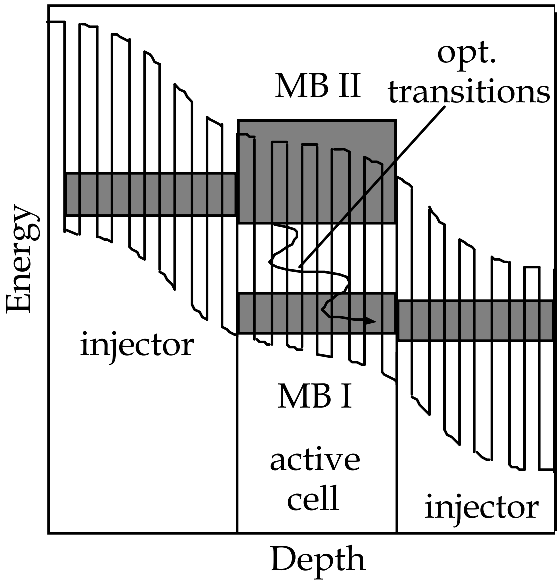

Fig. 2: Conduction band of the interminiband emitter

Two concepts of the active cells are known. The intersubband (ISB) concept is using typically three coupled quantum wells with three discrete energetic levels (Fig.1). Transition (3–2) is radiative. Transition (2–1) is tailored to have an energetic spacing around

36 meV (LO phonon energy in GaAs). It serves for fast extraction of the electrons from state two. Since the ratio of τ(3–2)/τ(2–1) lies in the order of 10, transition (2–1) is necessary to maintain population inversion. A superlattice, where the radiative transition across the minigap is used as an active cell of the interminiband concept (IMB) (Fig. 2). The internal field arising from the doping acts against the external field across the device which results in the band alignment depicted in Fig. 2. Electrons are tunneling from the injector into the miniband MB II. Optical transitions occur from the lowest state of MB II into the highest state of MB I and the electrons are free to move via the following injector into the adjacent active cell. Optical transitions between the higher states in the minibands appear at higher bias voltages. The active cell of the interminiband emitter can be a regular periodic superlattice or an aperiodic (chirped) superlattice. These modifications are used in order to maximize the optical dipole matrix element and to suppress the tunneling of the electrons from the upper states into the continuum.

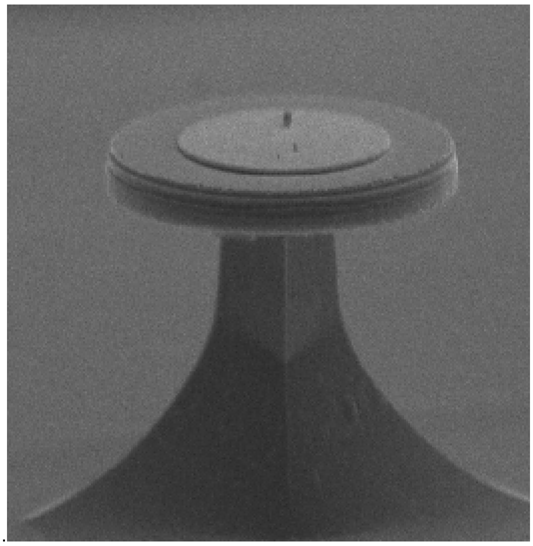

Fig. 3: SEM picture of a processed disk

The implementation of these emitters into a resonator enables lasing action. Optical confinement is achieved using cladding layers that are embedding the gain medium. An alternative concept with direct access of the current to the gain medium is a disk resonator (Fig. 3). It offers the possibility to study lasing action in the gain medium independently of any cladding layers. Lasing action can take place on the free standing periphery of the disk. Light is totally reflected on the boundaries of the disk and forms closed whispering gallery modes. Low threshold current and weak omnidirectional emission is typical for these lasers.

3. Experiment

Samples are grown using standard molecular beam epitaxy (MBE) [7]. They consist typically of about 500 layers. They are lithographically processed into ridges, mesas or disks (Fig. 3). Non alloyed metallic contacts are evaporated, before these emitters are soldered to a heat sink and bonded.

The current-voltage characteristics are measured at cryogenic conditions using both quasistatic and pulsed method. Parallel to pulsed I-Vs an integral output characteristics is recorded. Light is collected using f/0.7 optics and focused on a LN_2 cooled MCT detector. Since the emitted power of these devices lies in the range of nanowatts, correlation techniques must be used to detect the signal. Step-scan, Fourier transform spectroscopy [10] is used for the spectral analysis of the electroluminescence. Besides the emission measurements we perform photocurrent and transmission measurements as a complementary characterization of the emitters.

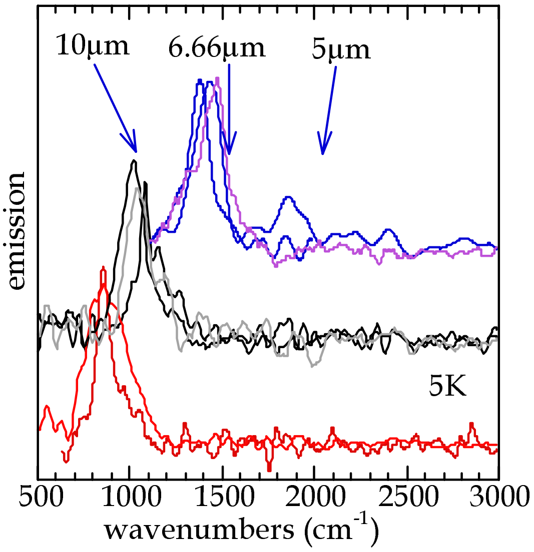

Fig. 4: Spectra of the unipolar QC emitters

Both intersubband and interminiband concepts are tested. Some of the measured spectra are depicted in Fig. 4. Emission wavelengths are covering the range between five and twelve µm. Peak quality (Position/FWHM) of 14 testifies outstanding quality of the growth and the used materials. The electroluminescent light was analyzed using a grid polarizer. High degree of TM polarization (up to 100%) was observed. Comparison of the peak maxima positions to the self-consistent calculation of the structures shows good agreement.

Trade-off between the requirement of high electrical conductivity and the optical parameters, like sufficient thickness and low absorbance of the cladding layers, appears to be the substantial problem on a way to electrically pumped laser. A disk resonator was fabricated. Measurements encountered problems with the inhomogeneous current distribution and did not allow to achieve lasing action.

4. Conclusion

GaAs/AlGaAs unipolar quantum cascade emitters have been designed, grown, and characterized. Optical and electrical methods are used for the investigation. We have demonstrated function of both intersubband and interminiband concepts as well as possibility of tailoring the wavelength from five to twelve µm. The measurement results are showing good agreement with the calculations, proving us outstanding quality of the technology.

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