Search for Plasma Instability Driven THz Radiation Sources

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GaAs/AlGaAs as a model material is a promising candidate for realizing coherent emission at long wavelengths. Utilizing quantum cascade emitters based on intersubband and interminiband transitions in the conduction band of a semiconductor, electroluminescence was demonstrated in the wavelength range from 3.3 to 85 THz. To our knowledge, the longest wavelength for electrically pumped lasing in a GaAs device is ≈ 23 THz [1]. All attempts to move beyond this value did not succeed so far. The performance of long wavelength devices is strongly decreased due to free carrier absorption. This is evident from an emission intensity dependence on the square root of the device current [2], which is a clear indication that electron-electron scattering in the upper excited level limits the nonradiative lifetime. That means that as long as this mechanism is dominant an increase in injection current does not lead to an increased emission. The emission intensity saturates and gain cannot be achieved as long as electron-electron scattering is the dominant nonradiative relaxation mechanism.

To circumvent this problem a collective excitation scheme is used to induce a plasma instability. The main difficulty with this kind of approach is that the starting bandstructure is changed significantly by the applied bias. Only at a given situation the mechanism of injection and extraction together with the proper energy level splitting will give a plasma instability.

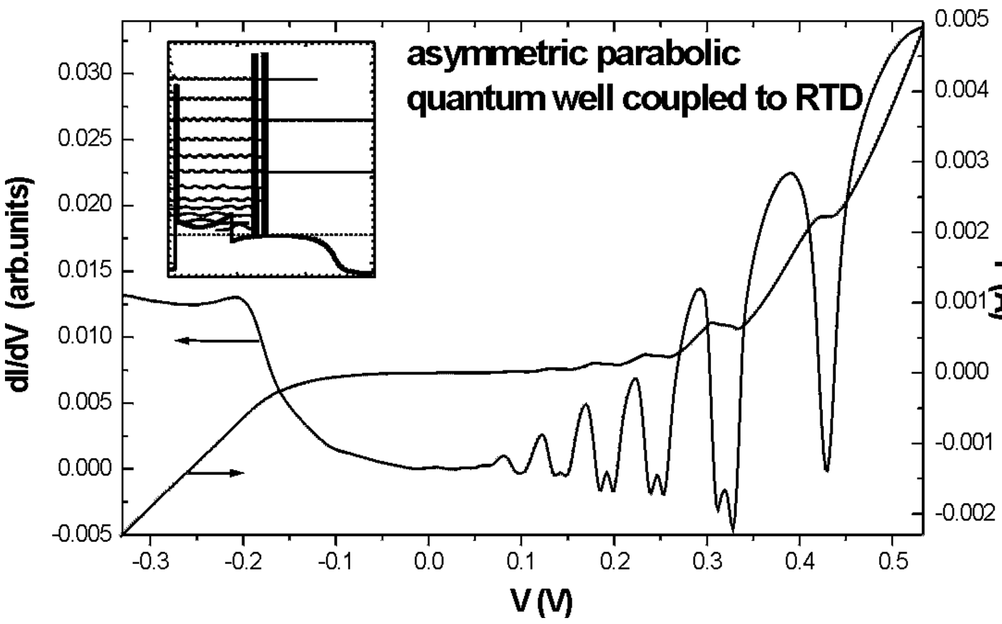

Fig. 1: Current and conductivity-voltage characteristic for sample G428. The sample is nominally undoped in the active region. The inset shows the band diagram.

We have done a first step in this direction by growing a new sample, without doping in the active region but compensating the doping by a parabolic potential (sample G428). The result is shown in Fig. 1, where the current and the derivative of the current are plotted as a function of the bias voltage. In the positive bias direction a spectroscopy of the levels above the Fermi level is performed. Each peak in the current represents the passing through a resonant level. For negative bias (forward direction) the levels below the Fermi level are scanned. This bias provides the situation for the extraction through the levels in the RTD and the pocket. The resonances in the derivative have become larger than in a previously grown sample G301 [3], but are still not visible clearly in the current. The extraction through the RTD is evident in the derivative at a bias of 0.2 V. This is the position to look for an instability.

This structure has also shown first emission results, however with a rather weak emission intensity [3]. An increase in emission is expected from cascaded structures. To cascade parabolic quantum wells similar to the situation in the QCL structures, a vertical injection scheme is favorable as has been reported recently by Maranowski et al. [4]. This cascading can be introduced by using bridging regions to combine different wells and offering extraction and blocking of carriers. A significant increase in the emission intensity was achieved with an experimental curve for a 30 μm mesa (sample G428) in forward bias.

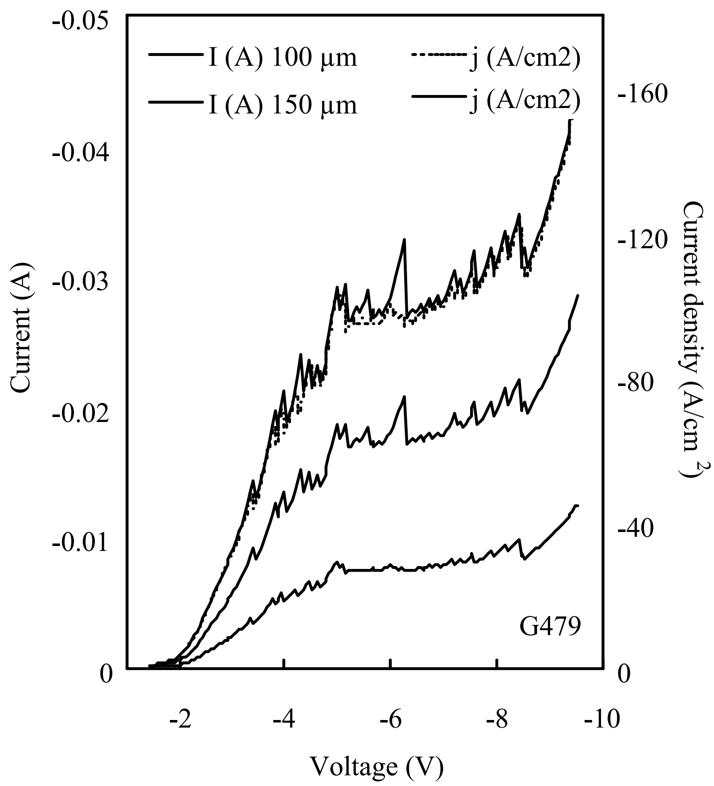

Fig. 2: Current-voltage characteristics and current density vs. external bias for two circular mesa structures processed into sample G479. The mesa diameters are 100 and 150 microns, respectively. The measurement are performed at liquid Helium temperatures.

We have previously demonstrated THz emission from parabolic quantum wells up to lattice temperatures of 200 K, where electrons are injected laterally in the parabolic well of carriers depending on the carrier energy [5]. In contrast to square wells, an extraction at low energies is specially critical, because the tunneling barrier gets thicker for lower energies, a direct consequence of the shape of the wells.

A cascaded parabolic quantum well structure (G479) consisting of 35 stages was MBE-grown on highly n-doped material to realize a homogeneous electron injection. A top layer with a carrier concentration of about 1-2x10^{18} cm^{-3} is to ensure a defined carrier injection. The well material is doped homogeneously to achieve an overall doping concentration in the active region of about 1x10^{16} cm^{-3} electrons per cubic centimeter, the barrier material is not doped intentionally.

For current-voltage measurements the samples are processed into small cylindrical mesas to probe the electrical behavior of the structure.

Figure 2 shows the current versus voltage and current density versus voltage behavior at low temperatures for two different mesa sizes to demonstrate the homogeneous injection of the electrons into the structure. The current densities are literally identical, the only detectable differences are in the regime where the structures breaks up into high and low field domains. This well known behavior reproduces a variety of peaks. The exact number of peaks has to be 35, so each well should be resolvable. The different mesa sizes are given in Fig. 2. The IV measurements are performed at cryogenic temperatures.

First emission experiments were performed with the cascaded plasmon structure sample G479 to repeat the experimental results of Maranowski et al [4]. We have processed the sample into stripes of 25 μm width and 1000 μm length. The emission sample consisted of 8 stripes giving a total emission area of about 0.228 mm^2.

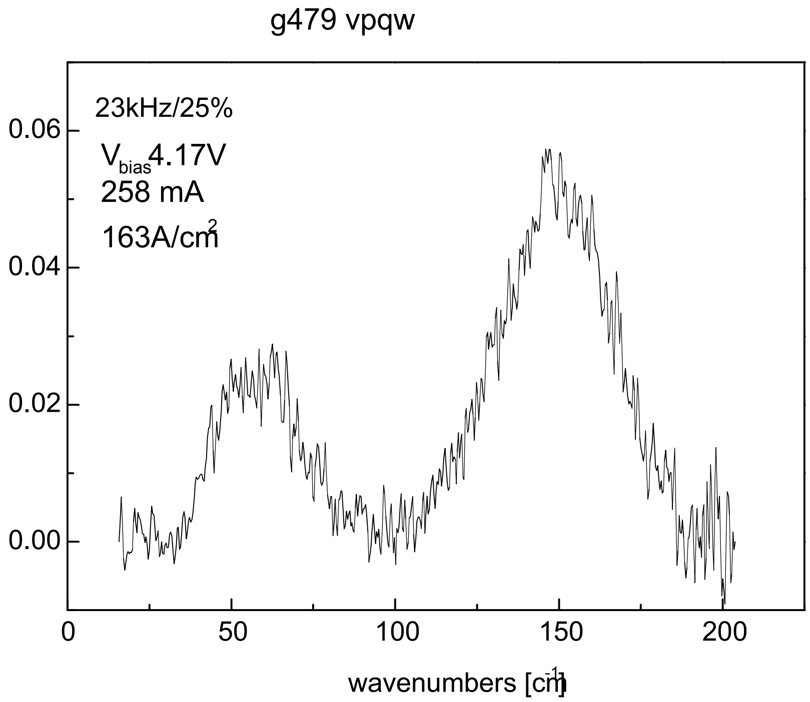

Fig. 3: Emission spectrum measured with a InSb detector as a function of the frequency (in wavenumbers).

The emission spectrum is measured with a InSb detector with a resolution of 10 wavenumbers. The spectrum consists of a main peak at 150 cm^{-1} corresponding to the plasmon energy of the parabolic bandstructure. This result is in agreement with the results of Maranowski et al. [4]. However we find an additional emission line at 60 cm^{-1}. The origin of this emission is not clear yet, it could be due to transitions between impurity states as it corresponds to the impurity ionization energy of close to 5 meV. Further investigations are under way.

References

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