

Terahertz magnetospectroscopy of high electron mobility CdTe/CdMgTe quantum wells

The extent of Terahertz (THz) radiation applications during last two decades has grown extensively as it was found to be useful in the fields such as medical imaging, security or drugs control to name just a few.

However, despite a tremendous work already done, the compact system of THz imaging operating at room temperature is still an issue.

Up to now, GaAs or GaN-based heterostructures and Si electron inversion layers were mostly used in solid-state THz optoelectronics. There, such a resonant phenomena as collective oscillations in a two-dimensional (2D) electron plasma and a free electron cyclotron resonance (CR) were observed.

When it comes about THz magnetospectroscopy in a high electron mobility CdTe-based QWs, not many reports in the literature can be found. Due to a polar nature of the crystal lattice bonds and relatively low optical phonon energies the influence of a polaron effect on cyclotron resonance as well as a plasmon-phonon interaction are much larger in CdTe than in the materials mentioned before. Better understanding of these fundamental effects is extremely important for the operation of the devices based on CdTe such as frequency tunable THz detectors, for example.

The goal of this work was to investigate the THz radiation induced effects in 2D electron plasma in CdTe-based QWs, concentrating an attention on the 2D plasmon excitation and peculiarities resulting from the polar nature of the material. The experiments were done on a high electron mobility CdTe/CdMgTe quantum wells, modulation doped with n -type impurity at one of the barriers (closer to the surface). All measurements were done at liquid helium temperature. A set of samples with a different parameters such as doping density and quantum well width were investigated in a photocurrent experiments. Also, transmission on samples containing a photo-lithographically formed metal grid-gate on the top was measured. A photocurrent induced in a quantum point contact (QPC) device defined by an electron beam lithography was also investigated.

In order to characterize the samples, magnetotransport experiments were done at first. The 2DEG concentration was found as well as electron effective mass and quantum scattering time by analyzing the oscillation period and amplitude of Shubnikov-de Haas oscillations. Also, the feature at Landau level filling factor $\nu=4/3$ was observed which might arise due to a Fractional Quantum Hall Effect (FQHE).

Photocurrent spectra as a function of magnetic field (B) and exciting the sample with a constant frequency radiation taken from THz laser were recorded. In some samples only a narrow cyclotron resonance (CR) peak was observed ($\Delta B_{FWHM} \sim 0.2$ T), while in the others optically induced SdH oscillations were present together with CR peak. The absence of SdH oscillations can be explained by the 2DEG heating due to bias current through the sample.

An interesting phenomenon was observed, when optically induced SdH oscillations were analyzed. The additional splitting at Landau level filling factors $\nu = 1, 2$ and 4 was observed. This phenomena might arise to the breaking of an Integer Quantum Hall (IQH) state due to THz radiation induced bolometric effect. However deeper investigation of the phenomenon is needed.

The next topic of the investigation was THz detection with a gated 2D electron plasma in CdTe/CdMgTe quantum wells. For this purpose a few samples with a deposited gold gate electrode allowing for the 2DEG concentration control with a voltage, were prepared. Here the SdH oscillations and a CR transition were observed and a non-monotonical dependence of CR peak magnitude on V_g was found. In general, changing the V_g it is possible to reduce the CR peak magnitude to the level of SdH oscillations, or to increase it to exceed SdH magnitude more than 20 times. Also, sample response at a few laser lines was measured as a function of the gate voltage at a constant magnetic field $B = B_{CR}$. The above described CR peak magnitude dependence on V_g or, in other words, a possibility to switch on and off the resonant detection was demonstrated. Another sample used for these experiments had a Hall bar geometry with a gated conduction channel. Experimental results also showed a non-monotonical CR peak magnitude dependence on the gate polarization. However, in this case the CR magnitude dependence on V_g showed well developed plateau regions.

Photocurrent spectra as a function of B were measured on a QPC sample. The device has a lateral gate and the conduction channel with the constriction of the form of a bottle-neck. Spectra were measured for a few laser frequencies and for a few gate voltage values. In both cases, CR maxima with a spectral features at low- B shoulder were registered. The spectral structures were found to represent the first and higher harmonics of electron plasma oscillations in magnetic field, also known as magnetoplasmons. It was found that plasmon frequency does not depend on the gate voltage, suggesting that detected plasma resonances form at the wide part of the channel, and not at the bottle-neck. Data analysis showed that plasmons observed are of ungated type and are confined in the conduction channel (width $W = 2.4 \mu\text{m}$).

In transmission spectra recorded on the grid-gated samples using the Fourier interferometer, the electron effective mass increase was observed at the strong magnetic fields which arises from the resonant polaron effect.

Transmission spectra recorded using the THz laser show a deep symmetric CR minimum for the reference sample (that without a metal grid). For the samples with the metal grid, on the low- B shoulder of CR dip, additional features were present. They were observed for two different laser frequencies and for two metal grids of a different periodicity. According to the theoretical calculations, these features are the first four harmonics of magnetoplasmons, with wavevectors defined by the period of the grating. These plasmons were shown to be a mixture of screened plasmons existing under metal fingers and unscreened plasmons existing in the openings of the grid. The proportion of plasmons of each type in the mixture were found to be approximately equal to the geometrical aspect ratio of the grating. Also, comparing experimental results with the theory it was found that the 2D plasmon frequency in n -doped CdTe/CdMgTe QWs of high electron mobility is strongly influenced by the plasmon-phonon interaction.

To sum up, resonant (cyclotron transition and 2D plasmons) and non-resonant (SdH oscillations) THz detection was demonstrated in the high electron mobility CdTe/CdMgTe QWs. Also, effects arising from polar nature of CdTe lattice were such as resonant polaron effect and plasmon-phonon interaction were shown to be important. To the best knowledge of the author 2D plasmons excited by THz radiation were demonstrated in CdTe/CdMgTe QWs for the first time.