# Intraband absorption of far-infrared light by electrons in GaAs/AlGaAs quantum wells

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**Abstract.**   In present work the first results of the investigations of intrasubband absorption of far-infrared polarized radiation ($\lambda \simeq 100~\mu$m) by equilibrium and hot electrons in GaAs/AlGaAs quantum wells are presented. The electrons were heated by strong longitudinal electric field. The experimental data was compared with theoretical ones taking into account nonequilibrium optical phonon, impurity and interface roughness scattering.

## Introduction

Absorption of middle- or far-infrared radiation due to intrasubband indirect transitions of electrons or holes plays an important role in design of optoelectronic devices for these spectral ranges. In particular, in middle- and far-infrared lasers the absorption of this type may limit the value of optical gain. Meanwhile the experimental investigations of absorption of this type in quantum wells (QW), as far as we know, had not been carried out. The published works have mainly theoretical character [1, 2], and deal with classical scattering mechanisms, namely interaction with phonons and impurities. Electron scattering on the nonequilibrium optical phonons and interface roughness were not taken into account.

The aim of this work is to study experimentally and theoretically the intrasubband absorption of polarized far-infrared range (FIR, $\lambda \simeq 100~\mu$m) radiation by equilibrium and hot electrons in GaAs/AlGaAs quantum wells.

## 1   The experimental technique

*The samples.* We studied GaAs/Al$_{0.22}$Ga$_{0.78}$As multiple quantum well structure consisted of 150 layers of 6 nm width QW divided by doped 14 nm wide barriers with 4 nm wide spacer. The electron mobility at $T = 77$ K was 3300 cm$^2$/(Vs). The electron surface concentration was $3 \times 10^{11}$ cm$^{-2}$ at $T = 300$ K. The diagram of quantum well structure is detailed in Table. 1. Experiment temperature was 4.2 K. Germanium hot hole laser was used as a source of FIR radiation. Photodetector Ge⟨Ga⟩ was used for registration.

Due to small width of quantum well the value of intensity modulation in electric field is also small. The way to increase this value is the use of multiple light passing through the structure. In order to provide this condition we used different techniques of FIR absorption investigations.

**Intraresonator measurements.**   The structure with QWs was placed into the resonator of FIR laser on hot holes in Ge, as it is shown in Fig. 1(a). The electric and magnetic pumping fields applied to laser are chosen in such a way that lasing is absent and only spontaneous emission can be observed. In this case a weak decrease of losses in resonator can lead to

**Table 1.** Diagram of quantum well structure.

| Buffer | 5 nm | GaAs | $N_D = 2 \times 10^{18} \text{cm}^{-3}$ |
|---|---|---|---|
| 150 times (MQW) | 6 nm | GaAs | undoped |
| | 4 nm | $Al_{0.22}Ga_{0.78}As$ | undoped |
| | 6 nm | $Al_{0.22}Ga_{0.78}As$ | $N_D = 1 \times 10^{17} \text{cm}^{-3}$ |
| | 4 nm | $Al_{0.22}Ga_{0.78}As$ | undoped |
| Buffer | 2 μm | $Al_{0.22}Ga_{0.78}As$ | $N_D = 5 \times 10^{16} \text{cm}^{-3}$ |
| | 2 μm | GaAs | $N_D = 5 \times 10^{16} \text{cm}^{-3}$ |
| Substrate | | semiinsulating GaAs | |

significant change of spontaneous radiation intensity. It is very sensitive technique allowing the observation of small changes of light absorption. Unfortunately, this method gives only qualitative information about absorption coefficient variation. It should be noted, that this method is applicable for study of light with s-polarization only but according to selection rules the intrasubband absorption is possible just in this case.

**Out of resonator measurements.**   For the quantitative measurements of light modulation in electric field we use the technique with total internal reflection geometry. The diagram of light transmission through the sample is shown in Fig. 1(b). This technique permits to obtain a value of absorption coefficient modulation, but some problems make difficult the precise calculations. One has to take into account two factors: (i) interference between beam incident on the structure and one reflected from vacuum–semiconductor interface [3, 4] and (ii) reflection from interface substrate-quantum layers. The presence of doped buffer layers in the structure affects both these processes and leads to effective decrease of light intensity inside the QW structure. This is of particular importance for FIR radiation when the structure dimensions are less than wavelength of radiation.

To avoid this difficulties the absorption of FIR radiation in equilibrium conditions was studied in traditional geometry (Fig. 1(c)).
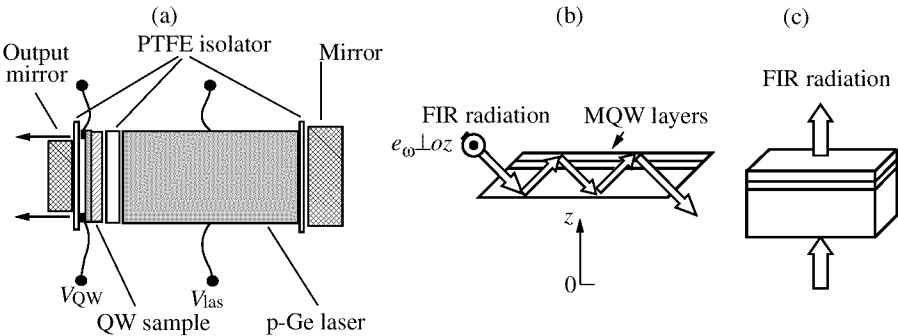


**Fig. 1.** Diagrams of experimental technique: intraresonator mesurements (a), total internal reflection geometry (b), traditional geometry (c).

## 2   The experimental results and discussion

The dependence of intensity of FIR radiation from germanium laser with GaAs/AlGaAs QW structures placed into the resonator (see Fig. 1(a)) on the applied electric field is shown in Fig. 2(a). One can see that there is a decrease of FIR absorption of QW structure in longitudinal electric field. Using this method we can not make some conclusion about the value of this decrease $\alpha(E)$, but we find that significant decrease of absorption occurs near $E = 200\,$V/cm. These results are consistent with ones obtained from out-of-resonator measurements (see Fig. 1(b)) shown in Fig. 2(b). Some difference between the results shown in Fig. 2(a) and 2(b) can be explain by the presence of strong magnetic field necessary for FIR laser operation in the first case.

The equilibrium absorption in the absence of electric field was measured in traditional geometry (Fig. 1(c)). The value of absorption coefficient $\alpha(0)$ was obtained taking into account reflection from both sides of the sample. These data are necessary for calculating the dependency $\alpha(E)$.

Let us discuss the experimentally observed dependence $\alpha(E)$ (Fig. 2(b)). We carried out the calculations of FIR radiation absorption coefficient due to intrasubband transitions of electrons taking into account nonequilibrium optical phonon, impurity and interface roughness scattering. Nonequilibrium optical phonons generated due to electron heating strongly affect the results of calculations. According to calculations the experimentally observed decrease of absorption coefficient is related to strong impurity and interface roughness scattering at low electron temperature. We suggest to explain the peculiarity of dependence $\alpha(E)$ by the presence of the impurity centers in the barrier near the interface. At low temperature these center can capture the carriers. Depopulation of this centers under electron heating leads to the change of free carrier concentration and to variation of $\alpha(E)$ from theoretically calculated.

The absorption of p-polarized FIR radiation in QW under electron heating in electric field was also investigated. These results have some difference from considered case that also can be explained using model of centers in the barrier.
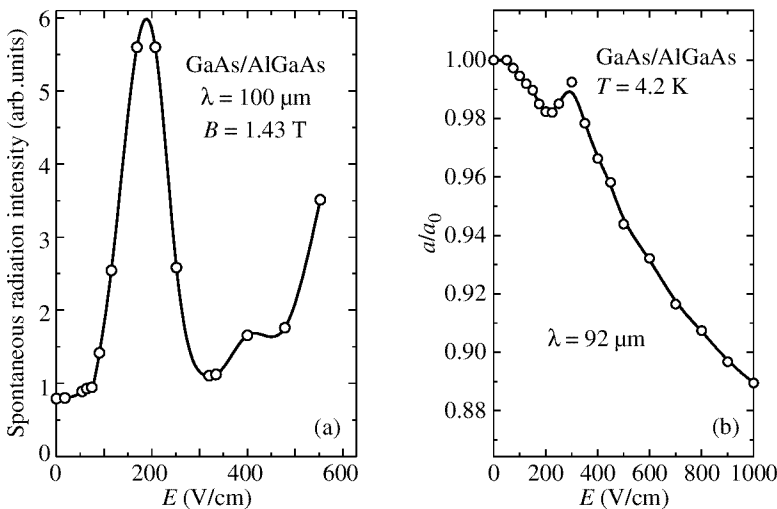


**Fig. 2.** Results of intraresonator measurements (a); change of the absorption coefficient of QW structure in longitudinal electric field (b).

### References

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