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The effect of stimulated interband emission on the impurity-assisted far-infrared photoluminescence in GaAs/AlGaAs quantum wells

I.S. Makhov [a, *], V.Yu. Panevin [a], A.N. Sofronov [a], D.A. Firsov [a], L.E. Vorobjev [a], M.Ya. Vinnichenko [a], A.P. Vasil'ev [b], N.A. Maleev [c]

[a] Peter the Great St. Petersburg Polytechnic University, 195251, St. Petersburg, Russia
[b] Submicron Heterostructures for Microelectronics Research and Engineering Center of the RAS, 194021, St. Petersburg, Russia
[c] Ioffe Institute, 194021 St. Petersburg, Russia

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ABSTRACT

Emission of far- and near-infrared radiations in the *n*-GaAs/AlGaAs quantum well nanostructures under interband photoexcitation of electron-hole pairs is studied at low lattice temperatures. Optical transitions of nonequilibrium electrons involving donor impurity states in quantum wells are revealed in far- and near-infrared emission spectra. Intensive optical pumping allows to observe near-infrared stimulated emission related to the radiative recombination of electrons from the ground donor state and holes from the valence subband in quantum wells. The possibility of the intensity increase of impurity-assisted far-infrared radiation due to effective depopulation of donor states with interband stimulated emission in quantum wells is demonstrated.

1. Introduction

For the last few decades, a lot of attention is attracted to investigation and development of far-infrared (terahertz) radiation sources, because of their potential application in the medicine, safety systems, ecological environment monitoring, wireless communications etc. [1–3]. One of the promising scheme for emitting far-infrared radiation associates with optical transitions of charge carriers involving shallow impurity states in semiconductors and semiconductor nanostructures. This is alternative to the well-known quantum cascade laser [4] of a very complicated technology. By now, several mechanisms of impurity-assisted far-infrared emission based on electrical and optical pumping have been observed. Thus, spontaneous terahertz emission caused by optical transitions of hot holes between excited and localized acceptor impurity states as well as with transitions from valence band to the ground acceptor state under impurity breakdown in *p*-Ge was observed in Ref. [5].

Under certain conditions, impurities in semiconductors can form resonant states that are located in conduction or valence bands. Stimulated terahertz radiation arising due to resonant acceptor states under carrier heating in strong lateral electric field in uniaxially stressed *p*-Ge was investigated in Ref. [6]. Furthermore, resonant impurity states were manifested in far-

* Corresponding author.
E-mail address: MakhovIS@spbstu.ru (I.S. Makhov).

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infrared electroluminescence spectra in the GaAs/GaAsN:Be microstructures with built-in stress [7] and in *n*-GaAs/AlGaAs quantum wells (QWs) [8].

Intraband or interband optical excitation were also used to obtain far-infrared luminescence. Thus, stimulated far-infrared emission associated with intracenter transitions of nonequilibrium charge carriers was observed in Si doped with donor [9,10] and acceptor [11] impurities under powerful intraband excitation with CO_2-laser. Experimental studies of spontaneous terahertz photoluminescence (PL) under interband photoexcitation in bulk *n*-GaAs and *p*-Ge have been reported in Ref. [12].

Sources of far-infrared radiation based on impurity transitions in structures with QWs should be more attractive than doped bulk semiconductors because of the possibility to control the impurity ionization energy in nanostructures due to the possibility to vary QW parameters. Actually, there are a few works devoted to investigation of far-infrared emission in doped QWs [8,13]. Recently, we have investigated far-infrared luminescence at low crystal lattice temperature in GaAs/AlGaAs quantum wells doped with shallow donors [14] upon interband optical pumping. The opportunity to control the terahertz emission frequency by a variation of QW parameters was also shown in Ref. [15].

In doped QWs, the mechanism of low-temperature impurity-assisted terahertz photoluminescence could be discussed using the optical transition diagram presented in Fig. 1. Under interband optical pumping (see $h\nu^{pump}$ wave in Fig. 1), electron-hole pairs are generated mostly in barrier layers. Then nonequilibrium charge carriers (marked as “minus” and “plus” circles) are captured in QWs; after that, electrons, originally living in the ground state of not ionized donor 1*s*, can recombine with nonequilibrium holes which have reached the top of ground heavy hole subband *hh*1. That recombination process can result in near-infrared photon emission ($h\nu^{near-IR}$ wave in Fig. 1). Further, nonequilibrium electrons, which also have reached the bottom of the ground electron subband *e*1, can be captured by electron-free 1*s* state of ionized donors. That electron-donor capture is a key process which could lead to far-infrared photon emitting ($h\nu^{far-IR}$ wave in Fig. 1). Possible electron capture to the excited donor states could leads to intracenter optical transitions. The experimentally observed in Refs. [14,15] terahertz emission bands in doped QWs were associated with the optical transitions of nonequilibrium electrons both from the ground electron subband in QW and excited donor states to the ground donor states in QW.

According to the mentioned above mechanism of impurity-assisted far-infrared photoluminescence in QWs one can see that far-infrared luminescence intensity is determined by the depopulation rate of the ground impurity state 1*s*. In this way, the increase of the depopulation rate of the ground impurity state 1*s* in QW should result in the increase of the terahertz photoluminescence intensity. One way to increase the depopulation rate of 1*s* impurity state is to provide stimulated emission due to optical transitions between the ground impurity state 1*s* and ground heavy hole subband *hh*1 in QW. Similar

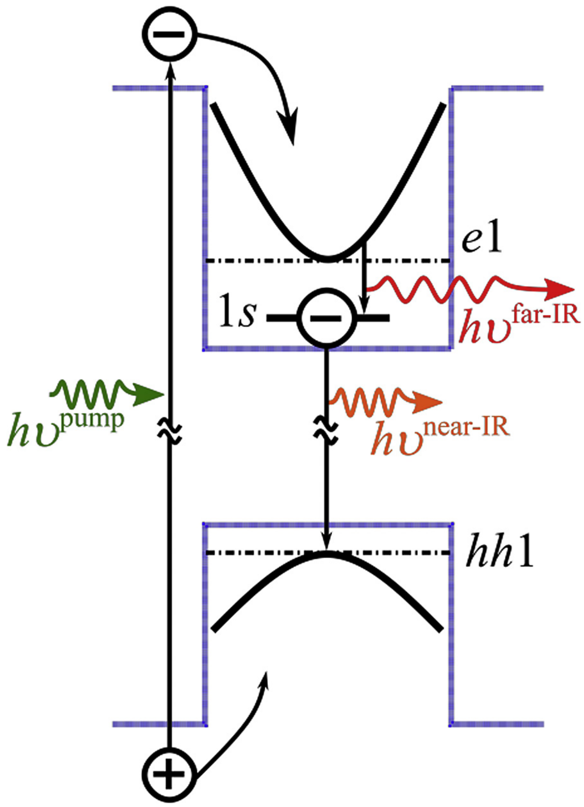

Fig. 1. Scheme of optical electron and hole transitions in quantum well with donor impurity under interband optical pumping.