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IMPACT IONIZATION DRIVEN CHAOTIC PHOTOLUMINESCENCE OSCILLATIONS IN $Ga_{0.47}In_{0.53}As$

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A new application of the Optically Detected Cyclotron Resonance (ODCR) is presented. We report impact ionization studies of bound exciton (BE) and shallow donor related recombination processes in $Ga_{0.47}In_{0.53}As$. An appearance of chaotic oscillations in photoluminescence (PL) intensity is observed under condition of impact ionization of deeper donors.

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1. Introduction

A new application of the ODCR [1, 2, 3] is presented. Irregular PL oscillations are studied. We prove that the driving force for these oscillations is an impact ionization process of excitons and donors by microwave heated free carriers.

2. Experimental

The ODCR studies were performed on a converted ESR spectrometer Bruker 200 D-SRC. 2 μm $Ga_{0.47}In_{0.53}As$ layers were grown by LPE method on a semi-insulating InP:Fe substrate with a 1.5 μm n-type 10^{17} cm^{-3} InP buffer layer. The residual donor concentration was gettered by adding into the melt a small amount of Yb. The resulting n-type epilayers were of a high purity with a free carrier concentration of 2×10^{15} cm^{-3} at 300 K.

3. Experimental results and discussion

In Fig. 1(a) we show the PL spectrum measured at 4 K under above band gap excitation of the epilayer. This spectrum consists of unresolved donor and acceptor BE recombination at 1531 nm (810 meV) [4] and donor–acceptor pair (DAP) transitions at 1562 nm (794 meV) [4, 5, 6, 7]. The better resolution could be obtained by applying microwave power at a CR condition. The microwave heated free carriers can impact ionize BE:s and shallow centers [3]. The spectral dependence of the impact process is shown in Fig. 1(b–d). This dependence clearly proves that the 1562 nm band consists of two subbands at 1555 nm and 1572 nm. We attribute these bands to two DAP transitions involving two different donor species of slightly different ionization energies.

A new microwave induced effect is observed when the excitation intensity is increased by 15% (Fig. 1(e)). Irregular oscillations are observed affecting the intensity of the whole PL spectrum. These oscillations occur at and above the threshold field for impact ionization of the deeper donors. The "frequency" and magnitude of the oscillations changes strongly with a change in microwave power. First, smaller quasi-regular oscillations are observed, which rapidly increase in intensity with an increase in microwave power. For the maximal microwave power applied (200 mW) these oscillations were irregular and showed a multi-frequency character (Fig. 2).

Such features of these oscillations are consistent with a Schöll model proposed to explain self-generated chaotic current/voltage oscillations [8, 9, 10]. Carriers impact ionized from shallow donors and excitons are immediately recaptured by deeper donors. At increased fields we reach the threshold for impact ionization of deeper centers. This affects profoundly the free carrier concentration. It increases, but simultaneously the concentration of hot carriers is reduced. This is because they are now cooled down rapidly due to impact processes and enhanced free carrier and ionized center scattering. The free carrier trapping rate depends on effective carrier temperature [11, 12]. In consequence, cooling enhances their recapture by both shallow and deeper centers and results in a decrease in free carrier concentration. Reduced concentration of free carriers and ionized centers leads to faster heating (reduced scattering) and, thus, to impact ionization of shallow and deeper centers. This closes the cycle and explains why such oscillations can occur. In previous work the resulting oscillations were observed *only* as chaotic changes in current or voltage. We report here the first prove that such changes

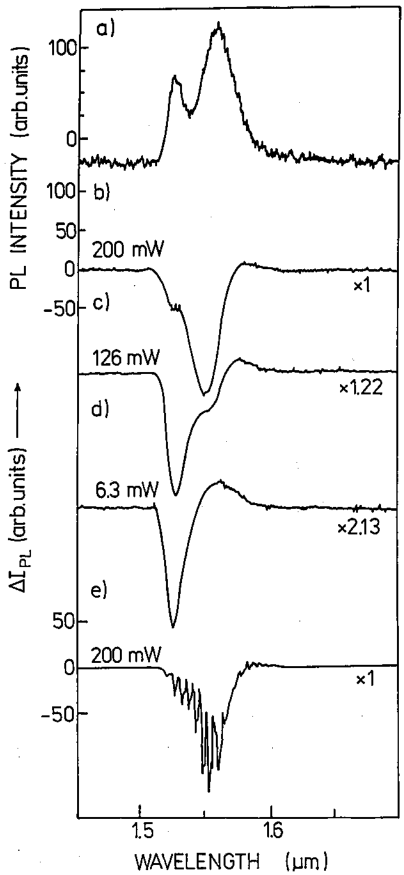

Fig. 1. PL spectrum of GaInAs epilayer measured at 4 K under above band gap excitation (a). In (b–d) spectral dependence of PL response to microwave power (200–6.3 mW) is shown. Negative signal means that intensity of a given process is reduced due to impact ionization of an exciton or shallow donor state. In (e) microwave induced irregular PL oscillations are shown. These oscillations were observed as temporal changes in intensity of a whole PL spectrum. The ODCR signal was detected in phase with a microwave power chopped at 6.25 kHz.

are accompanied by irregular oscillations in PL intensity. Moreover, by comparing threshold fields for impact ionization and PL oscillations we could prove directly that impact ionization process is a driving force for chaotic oscillations in the free carrier density. This confirms the theoretical model of Schöll.

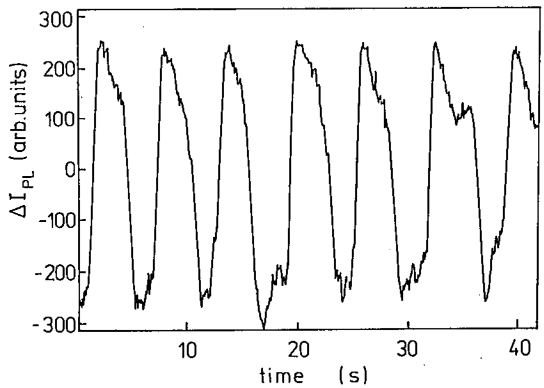

Fig. 2. Time dependence of chaotic PL intensity oscillations. The temporal PL changes were measured for detection set at 1572 nm DAP band and 200 mW applied microwave power with magnetic field set at cyclotron resonance condition.

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