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EVIDENCE OF Γ-FREE OR BOUND-TO-DEEP ACCEPTOR CHARACTER OF THE Y-1.2 eV DEEP PHOTOLUMINESCENCE LINE IN n-type Ge-DOPED GaAs DERIVED FROM HIGH HYDROSTATIC PRESSURE EXPERIMENTS IN DIAMOND ANVIL CELL*

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The dependence of the energy position of the deep defect-related photoluminescence line Y-1.2 eV in Ge-doped GaAs on high hydrostatic pressure is investigated using a Dunstan-type diamond anvil cell. The observation that the energy position of the line follows that of the Γ-conduction band minimum in the 1 bar–30 kbar pressure range demonstrates that the line has Γ-(free or shallow bound)-to-deep acceptor character. This fact confirms the deep-acceptor character of the deep defect, most likely a donor impurity–Ga vacancy complex, which contributes to the Y-1.2 eV photoluminescence line.

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Identification of the origin of a deep defect-related photoluminescence line of a bulk semiconductor requires that an answer to the following question should be found: which of the two particles involved, electron or hole, or may be both — is deeply bound. In this paper we describe one possible way of approaching this question. We investigate the pressure dependence of the energy position of the line using the diamond anvil high pressure cell technique. The technique is applied for observation of the deep Y-1.2 eV (at ambient pressure) photoluminescence of a Ge-doped GaAs sample and confirmation of the deep-acceptor character of the deep defect responsible for the luminescence is obtained.

The Y-1.2 eV photoluminescence is the most commonly observed deep luminescence of impurity doped n-type GaAs [1]. It is observed in GaAs doped with group IV and group VI impurity atoms. The energy position of the line is weakly species-dependent: from 1.18 eV for Si to 1.22 for Se [1], and the halfwidth of the line at 10 K is about 0.15 eV. The 1.2 eV line is believed to originate from a donor impurity–Ga vacancy deep acceptor complex [1]. This identification was derived from different experiments reviewed in Ref. [1], involving investigations of free-carrier concentration versus impurity concentration studies, annealing studies, stoichiometry considerations, various aspects of luminescence studies and analogies with so-called self-activated (SA) luminescence in II–VI compounds.

We report here on investigations of the Y-1.2 eV line in a Ge-doped MOCVD-grown 2 μm thick epilayer of GaAs, LID1304. The carrier concentration in the sample derived from 300 K Hall measurement is $n_{\mathrm{H}} = 1.1 \times 10^{17}$ cm^{-3}. We employ Dunstan-type [2] diamond anvil high pressure cell, which allows the pressure to be changed *in situ* at cryogenic temperatures. Argon is used as a pressure transmitting medium. The sample of size of approximately $100 \times 100 \times 30$ μm^3 is placed in the 250 μm diameter hole in a stainless steel gasket preindented to a thickness of 100 μm. A laminated gasket technique [3] with 100 μm hole in the 50 μm thick screening part of the gasket is used to allow transmission and luminescence to be measured alternately with the same optical set-up. The white light for transmission measurements is provided by a halogen bulb lamp and multi-wire quartz fibre. Green argon-ion laser light is used for excitation and the luminescence light is dispersed by a 1.0 m double-grating SPEX monochromator and detected with a Si-avalanche photodiode detector. The pressure is calibrated using the shift in energy of the band-edge transmission onset of the sample, which is governed by the band-edge absorption of the semi-insulating GaAs substrate. The GaAs Γ-band-edge shift is taken to be 10.73 meV/kbar [4].

The photoluminescence spectrum of the sample at a pressure of 8.5 kbar is given in Fig. 1. The spectrum is dominated by near-band-edge band-to-band (eh) 773 nm (1.603 eV) and band-to-acceptor (eA) 780 nm (1.589 eV) transitions which correspond to 1.513 eV and 1.495 eV lines at ambient pressure. The Y-line is observed at 942 nm (1.316 eV) at 8.5 kbar. At 9 kbar pressure the shallow-deep A_1 transition for Ge-donors takes place [5, 6]. This transition results in drastic quenching of free electron concentration in the conduction band. Consequently, the band-to-band (eh) luminescence is quenched and the shallow-Γ-donor–shallow acceptor (eA) luminescence dominates the near-band edge photoluminescence in the 10–30 kbar range. The shallow Γ donors involved are no longer germanium

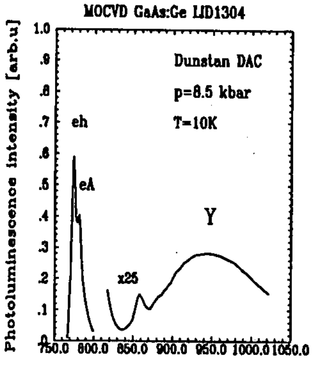

Fig.1

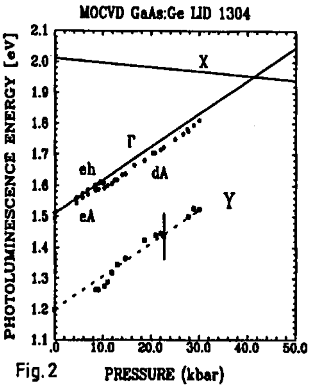

Fig. 2

Fig. 1. Photoluminescence spectrum of n-type GaAs:Ge at 8.5 kbar hydrostatic pressure. eh and eA stand for band-to-band and band-to-acceptor near-band-edge luminescence and Y for the deep defect related luminescence investigated in this paper. 860 nm line corresponds to the C line of Ref. [1] identified as conduction band to deep Cu acceptor transition.

Fig. 2. Pressure dependence of the energy position of the Y-line versus the near-band-edge luminescence. The error bar corresponds to the observed half-width, about 0.15 eV, of the Y line.

as the ground state of this donor is now deep. Residual (most likely Si and S) donors [6, 7] govern the luminescence. The strong localization of the deep A_1 state of germanium donor makes the possible germanium-related luminescence much weaker than any luminescence involving Γ-shallow large radius donor states of residual impurities. The change in the character of the main Ge-donor close to 10 kbar does not affect significantly the Y-line. The width of the line, about 0.15 eV FWHM — see an error bar in Fig. 2, does not change its magnitude in the 1 bar–30 kbar pressure range. The pressure coefficient of the energy position of the maximum of the line is, within experimental error, equal to that of Γ-conduction band (as depicted by dashed line in Fig. 2) for pressures up to 30 kbar, i.e. as long as the residual impurity donors remain shallow Γ-bound [6]. The observation of the Γ-like pressure coefficient for the deep photoluminescence line Y allows us to exclude two possibilities: i) both, electron and hole involved in the transition are strongly localized, i.e. the transition is an inter-deep-defect transition; ii) a deep-non-Γ-donor is involved in the donor-acceptor (shallow or deep) transition. In both cases the line would not follow the near-band-edge emission.

The most likely explanation of observed pressure dependence of the line is that the transition has a Γ-free or Γ-shallow bound-to-deep acceptor character. This interpretation gives further support for the model in which the donor impurity on Ga site–Ga vacancy complex is a deep acceptor contributing to the Y-1.2 eV deep photoluminescence of n-type impurity doped GaAs.

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