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PRESSURE INDUCED SHALLOW-DEEP A_1 TRANSITION FOR Sn DONOR IN GaAs OBSERVED IN DIAMOND ANVIL CELL PHOTOLUMINESCENCE EXPERIMENT*

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Variable-pressure Dunstan-type diamond anvil high pressure cell and a low temperature photoluminescence technique are used to observe the shallow-deep A_1 transition for Sn donors in highly Sn doped n-type ($\approx 10^{18}$ cm^{-3}) GaAs. Fermi level pinning to the position of the deep Sn donor state entering the gap close to 30 kbar pressure is observed. Drastic narrowing of the near-band-edge luminescence is observed in the transition region. The deep-donor pressure coefficient of 2 meV/kbar with respect to the valence band is deduced from the energy position of the deep donor–acceptor transitions.

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At the XX Jaszowiec School we reported on high-pressure magneto-optical investigations of high purity weakly Sn doped GaAs [1]. The shallow Γ-donor state of Sn impurity could be observed up to 30 kbar only. Above this critical pressure the shallow donor absorption was persistently quenched due to the electron trapping onto the deep non-metastable donor state.

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In this communication we report on the investigations of the properties of this deep donor state with low temperature photoluminescence and a variable pressure Dunstan-type [2] diamond anvil cell high pressure technique which allows the pressure to be changed *in situ* at cryogenic temperatures. We investigate a highly Sn doped ($n \approx 10^{18}$ cm^{-3}) bulk GaAs sample. The sample of a 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. Argon is used as a pressure transmitting medium. 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 on-set of the sample. The GaAs Γ-band-edge shift is taken to be 10.73 meV/kbar [4].

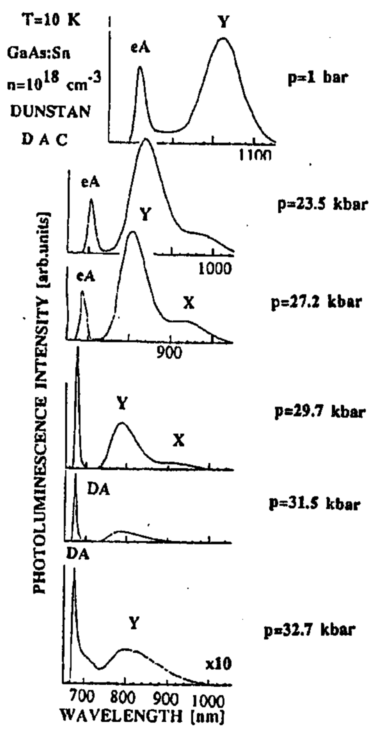

Fig. 1. Low temperature (10 K) photoluminescence spectra of n-type GaAs:Sn ($n \approx 10^{18}$ cm^{-3}) at high pressures. Different spectroscopic features are marked: eA — conduction band to shallow acceptor transition; DA — deep donor state to shallow acceptor transition; Y, X, — deep photoluminescence bands.

The low temperature (10 K) photoluminescence spectrum of the sample at ambient pressure is characteristic of a highly doped degenerate semiconductor (Fig. 1). The near-band-edge luminescence line is slightly asymmetric with the high-energy slope steeper, characteristic of transitions from a conduction band filled with electrons up to the Fermi level. For $n \approx 10^{18}$ cm^{-3} and parabolic band the Fermi level is expected to be 52 meV above the bottom of the conduction band [5]. The half-width of the line corresponds well with this estimate. The width, shape and energy position of the maximum of the line at 1.512 eV, analogous to those reported for highly Te [5] and Si [6] doped GaAs, allows us to follow authors of Ref. [5] and [6] and attribute this line to indirect recombination of free electrons up to the Fermi level and acceptor-like localized states (eA) [5, 6]. At lower energies a broad deep Y-1.2 eV luminescence band is observed characteristic of n-type highly doped GaAs [7]. Upon applying pressure both features follow the conduction band edge up to 28 kbar without there being a significant change in intensity and shape of either feature. In the 28–32 kbar range there is a significant change in the near-band-edge luminescence line shape: the line first becomes narrow and later on loses intensity evolving into a broad band with a well-defined high-energy edge. This drastic change in photoluminescence coincides approximately with the quenching of shallow donor absorption reported previ-

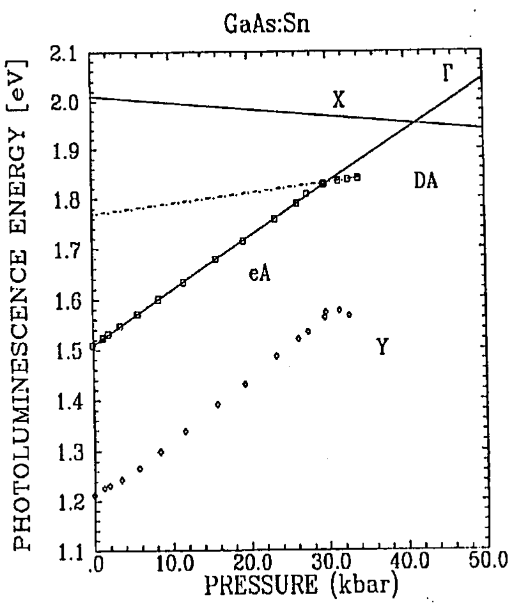

Fig. 2. Pressure dependence of different spectroscopic features for GaAs:Sn. The points correspond to the spectroscopic features presented in Fig. 1: eA, DA and Y. Solid lines (Γ, X) correspond to the pressure dependence of the energy positions of the conduction band minima Γ and X with respect to the top of the valence band for GaAs at 10 K.

ously to occur above 30 kbar pressure [1]. We can thus attribute the narrowing of near-band-edge luminescence to a metal–nonmetal transition when the highly localized deep Sn state enters into the gap. The Fermi level becomes pinned at this deep donor state upon crossing the conduction band edge. The position of the high-energy edge of the luminescence corresponding to the Fermi level moves with a pressure coefficient of approximately 2 meV/kbar with respect to the valence band (Fig. 2). This pressure coefficient is similar to the previously observed pressure coefficients of the Ge deep A_1 level derived from far-infrared spectroscopy (2.1 meV/kbar with respect to the valence band) [8] and 1.8–2.7 meV/kbar reported for Si donor [6, 9, 10] from photoluminescence. The observation of similar pressure coefficients for all group IV donors which differ from those for group VI donors ($\approx$ 0 meV/kbar [11–13]) is consistent with theoretical calculations of energy levels of localized A_1 states of different substitutional donor impurities [14].

Thus we can conclude that we observe a deep non-metastable state of the Sn donor which enters the gap above 30 kbar and has properties characteristic of deep A_1 state of substitutional donor impurities, similar to previous reports for Ge, Si, S, and Se donors in GaAs.

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