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METAL - INSULATOR TRANSITION STUDIES BY PHOTOLUMINESCENCE ON Sn-DOPED GaAs EPITAXIAL LAYERS.

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ABSTRACT

Using the liquid phase epitaxy (LPE) growth technique, Sn-doped GaAs epitaxial layers were grown with impurity concentrations of around 10^{17} cm^{-3}. For this level of n-type doping the semiconductor is near metal-insulator transition. These layers were characterized by measuring their photoluminescence spectra (PL) in the temperature range between 12 and 300 K and laser power ranging through three decades. The spectra showed an excitonic band that mixes the exciton transitions, and also a broad band where the free-to-bound and donor-acceptor are present. The evolution of the peak intensities, peak energy positions and half-width of the different bands as a function of temperature are discussed. We compared the spectra for concentrations lesser and greater of metal-insulator transition concentration in order to prove that this transition does not occur abruptly.

RESUMEN

Se le hizo fotoluminiscencia a una muestra de GaAs crecida por Epitaxia en Fase Líquida y dopada con Sn con concentraciones alrededor de 1x 10^{17} cm^{-3}, muy cercana a la transición metal- aislador. Se varió la temperatura desde 12 hasta 300 K y la potencia de excitación se cambió en tres ordenes de magnitud. Los espectros mostraron que las transiciones del excitón libre y los excitones ligados se mezclan en una sola banda, mientras que las transiciones libre a ligado y donador-aceptor igualmente forman una sola banda. Se estudian en este trabajo las intensidades, posiciones y anchos de cada banda. Se comparan los resultados de los espectros de PL para las muestras dopadas con concentraciones de impureza menores y mayores para que ocurra la transición metal-aislador para demostrar que esta transición no ocurre abruptamente.

INTRODUCTION

The high doping of GaAs epitaxial thin films is a very attractive topic study due to their large aplicability in optoelectronic [1-4] and in high-speed devices [5].

The metal-insulator transition (M-I) on heavily doped semiconductors has recived considerable interest in recent years [7]. Theoretical investigations have produced conflicting results [8]. The essential features of the various models may be summarized as follow: A transition as a result of correlation has been proposed by Mott to occur when

$$a_b\, n^{1/3} \approx 0.75 \quad \text{(the Mott criterion)} \quad (1),$$

where a_b is the Bohr radius of an electron in the semiconductor and n is the impurity concentration. The transition from an insulator to a metal occurs when the impurity band

and electronic band overlap. The same criterion is found when the transition is due to disorder, that is, the Anderson transition. In this case the transition occurs when the Fermi energy moves from a region of localized states to a region of extended states. In both models the transition is continuos but abrupt as the classic solid-liquid transition.

In this paper the metal–insulator transition is studied by means of the photoluminescence spectroscopy (PL) on n-type GaAs : Sn samples in order to prove that this transition does not occur abruptly.

EXPERIMENT

The thin films n-type GaAs: Sn were grown by Liquid Phase Epitaxy (LPE) in excess of As, to guarantee that the samples resulted n-type. These samples were grown on substrates of GaAs and in impurity concentrations with 1×10^{17} and 5×10^{17} cm $^{-3}$. The spectra of photoluminescence were taken under the following arrangement: the line 488 nm of a laser of Ar LEXEL 95 was used as source of excitement. The issued light was gathers by SPEX 500 M a spectrometer and this luminescence was measured with a HAMAMATSU R2658 photomultiplier coupled to an " lock – in " Amplifier tuned to 83 Hz.. The sample was cooled through a He liquid system.

RESULTS

The spectra for different concentration samples are shown in fig. 1. For the 1×10^{17} cm^{-3} concentration sample, which is very close to the M-I transition, the spectrum shows two peaks clearly: the A peak, known as the excitonic peak or also known as the band edge transition, and the B peak which is an overlapping of a free to acceptor transition, in the highest energy side of the band, and a donor to acceptor transition (DA). Since Sn is an amphoteric material the acceptor concentration is not negligible. Due to the fact that the Sn ionization energy is 6 meV when behaving as a donor [9], these two last transitions are very close.

In this paper we propose that the band edge transition results from three transitions: 1) an established transition in which is not conserved, from the nearby regions at electron quasi-Fermi level to the edge of the valence band (XC1) [3,5,10,11], 2) the other established transition in which is conserved, from the parabolic region of the conduction band or from the band tail to the edge of the valence band or its band tail (XC2) [3,5,10,11] and 3) a transition from the donor impurity band to the acceptor impurity band (XC3) [5]. As a first approximation we propose gaussian-shape curves for those transitions [12]. This is a generalized method to obtain physical information in PL spectra in low doping semiconductor. This information is not exact but sufficiently good . As an example, fig. 2 presents the deconvolution process with three gaussian peaks. A similar deconvolution process was accomplished for the 5×10^{17} cm^{-3} concentration sample.

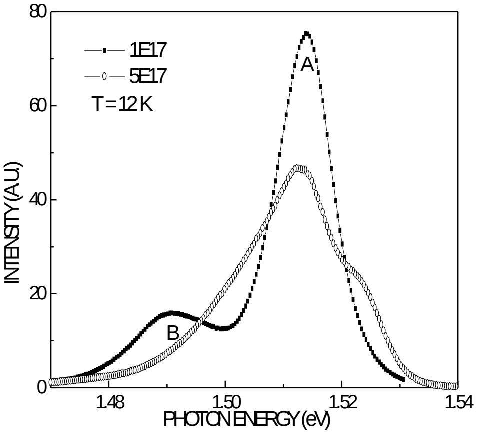

Fig. 1. PL spectra for two different concentrations. A and B peaks are explained in the text

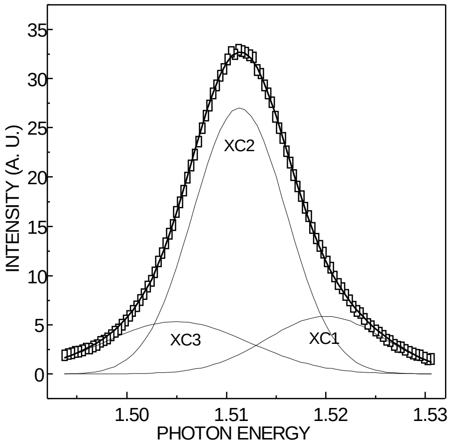

Fig 2. Deconvolution with three gaussian peaks for the band A for n=1x10^{17} at 50K. The squares are the experimental points and thethick line a three Gaussian lineshape fit.

The fitting with the gaussian curves gave the height, the band half-width and the energy position.

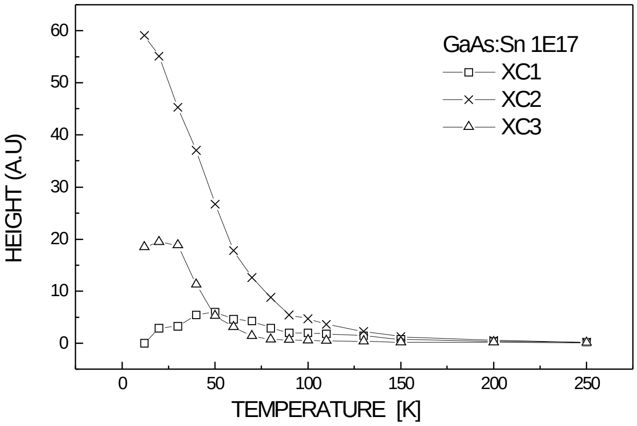

Fig. 3. Variation of the height with the temperature.

The variation of the heights , fig 3, of the different gaussian peaks with the temperature are as follows: a) for temperatures lower than 50 K the XC1 peaks intensity increases with temperature; while for higher temperatures the intensity shows a drastic decrease as it is expected for a band to band transition, b) the XC2 peaks present an exponential fall, typical of excitonic peaks, and c) for low temperatures, the XC3 peaks seem not to have a dependency with temperature but, higher temperatures, the intensity shows a sharp fall; this type of dependence is similar to the DA transition behavior.

Fig. 4 shows the energy positions of the gaussian curves for $5x10^{17}$ cm^{-3} concentration sample. For comparison effects the gap energy Eg, is plotted as a function of temperature, T, and of concentration, n, using the expression [6]:

$$Eg(T,n) = 1.519 - 7.3x10^{-8} n^{-1/3} - \frac{5.405x10^{-4} * T^{2}}{T + 204} \tag{2}$$

The energy distance between the XC1 peak and the gap increases with temperature, due to the increase of the Fermi level energy, as it is evident in fig.4. As it is known, the excitonic peaks move along with the gap as well as the XC2 peak. This sample should not exhibit excitonic peak because the impurities destroy the exciton bound , then we propose that the presence of the high excitonic peak is due to regions where the impurities are far, that is, the impurities are inhomogenely distributed. When the temperature increases the XC3 peak moves toward lower energy faster than the gap shift does. This is a consequence of the fact that when the temperature increases the closer donor - acceptor pairs are thermally depopulated before the farther pairs do. Since the coulomb interaction decreases with the distance between donor-acceptor pairs, the transition energy diminishes. Moreover, for XC3 peak, the gaussian curve height of the higher concentration sample falls with temperature faster than the lower one, which is due to the overlapping that occurs between the donor impurity band and the conduction band while the temperature increases.

The excitonic A peak does not change its energy position when the laser power varies. This happens because the photogenerated electrons drain to the donor band, since there is a transition from the donor impurity band to the acceptor impurity band [9], as it was already mentioned for the XC3 curve. The existence of DA transitions in the *A* and *B* bands spectra reflects the lack of homogeneity of the impurity distribution. In *B* band the transitions involve impurities with ionization energies of E_A = 30 meV and E_D = 6 meV, similar to those reported by Pankove [9] for lightly doped zones, while transitions in *A* band correspond to lower ionization energies due to the diminution of the energy for effect of the impurities high concentration [13].

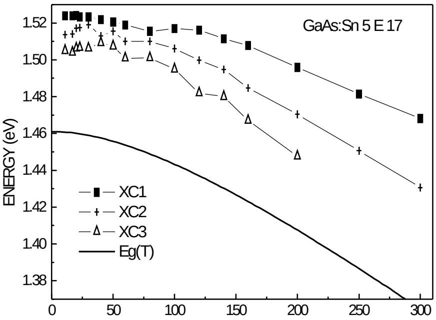

Fig. 4. Gaussian peaks energy shift with Temperature

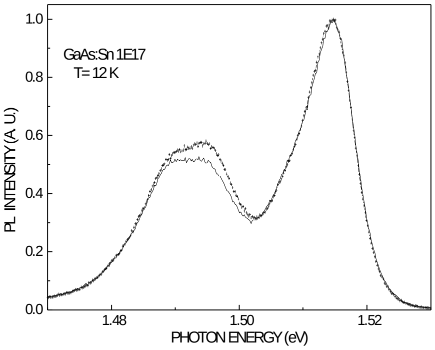

Fig. 5. PL spectra for n = 1x 10^{17} in two different places of the sample

CONCLUSIONS

The previous results lead to the conclusions that the M-I transition in semiconductors is not a sudden outcome but it is rather a region process within the material because impurities are not homogeneously distributed. That is, there are zones of high impurity concentration like islands. The sample has a metal behavior when the islands have contact points and the electrons percolate. The increase of the impurities concentration enlarges the high concentration zones. In fig. 5 are shown the spectra taken at different places for a single sample that makes the lack of homogeneity of the impurities distribution evident. The difference in the free to acceptor transition peak is due to a local increase in the acceptor density.

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