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ELECTRON ACCUMULATION AT THE n-ZnSe/n-GaAs INTERFACE

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Des résultats soutenant la présence d'une couche d'accumulation électronique dans le ZnSe, à l'interface de l'hétérostructure n-ZnSe/n-GaAs, sont présentés. Une couche tampon de GaAs de type n, de 1 μm d'épaisseur, avec une concentration électronique initiale de l'ordre de 10^{15} cm^{-3} , que l'on a fait croître sur un substrat semi-isolant de GaAs d'orientation (100), se trouve être totalement vidée de ses électrons lorsque l'on fait croître sur elle une couche épitaxiale de ZnSe de type n. La concentration électronique de la couche tampon se trouve rétablie quand le ZnSe est retiré par une attaque chimique sélective. La conductance correspondante à cette couche de ZnSe décroît logarithmiquement avec la température, passant à une conduction d'activation au-dessus de 6K, du fait d'une forte localisation. Ce comportement est caractéristique d'un système bi-dimensionnel.

ABSTRACT

Evidence for electron accumulation in the ZnSe side of n-ZnSe/n-GaAs heterostructures is presented. An n-GaAs buffer layer, approximately 1 μm thick, grown with low 10^{15} cm^{-3} electronic concentration on a semi-insulating (100) GaAs substrate is fully depleted of electrons when an additional epilayer of n-ZnSe is grown on top of it. The n-GaAs epilayer electron concentration is restored when the ZnSe is removed by selective etching. The corresponding conductance of the n-ZnSe decreases logarithmically with temperature, going over to activated conduction below 6 K due to strong localization, a characteristic of a 2-D system.

In recent years, the growth by both MOCVD and MBE of ZnSe on GaAs has resulted in a great improvement in the optical properties of ZnSe epitaxial layers¹. For relatively thick lightly doped ($n \sim 5 \cdot 10^{16} \text{ cm}^{-3}$) n-ZnSe epilayers grown on semi-insulating (SI) GaAs substrates the transport properties are well understood: the conduction electron concentration is governed by thermal excitation from donor impurities, the corresponding mobility being considerably reduced by large compensation². Nevertheless, when the transport properties are compared for different epilayer thickness (t) in the submicron to micron range³, they are singularly unusual in that the average room T resistivity of nominally

undoped n-ZnSe on SI GaAs increases with t . In addition, the usual free exciton photoluminescence (PL), which is at 2.8015 eV for thick ZnSe samples, was found to be shifted to higher photon energy for submicron thick ZnSe grown by MBE, namely to 2.8054 eV for ZnSe on GaAs substrates⁴ and 2.8064 eV for ZnSe on a GaAs buffer layer⁵. The latter⁵ demonstrated by RHEED that nucleation of ZnSe on the GaAs epilayer proceeded by a 2-D growth mechanism and accounted for the 5 meV shift in PL by valence band splitting due to the uniform tetragonal lattice distortion. Recently, we have reported the electronic Raman spectrum of neutral acceptor impurities, identified as phosphorus in undoped compensated n-ZnSe on a GaAs buffer, the non-equilibrium population being generated by below band-gap laser light⁶. This spectrum showed a Γ_8 ground state splitting of 52 cm^{-1} in agreement with deformation potential estimates for a uniform lattice distortion due to the 0.24% mismatch.

The ZnSe epitactic layers used in this study were deposited on (100) GaAs substrates by low pressure MOCVD using dimethylzinc and H_2Se diluted with H_2 as source materials. At growth temperatures below 350°C , highly resistive layers are observed, but at 400°C and above they are conducting. Assuming a uniform electron distribution across the epilayer, the electron concentration at room T varied from $1.4 \cdot 10^{18} \text{ cm}^{-3}$ to $1.7 \cdot 10^{17} \text{ cm}^{-3}$ as t varied from $0.05 \mu\text{m}$ to $0.55 \mu\text{m}$ for a number of samples grown on SI GaAs at 400°C under identical conditions except for growth time. The results indicate the presence of a very conducting layer near the interface, the origin of which was examined in the following way. Two $1.1 \mu\text{m}$ thick n-GaAs epilayers (samples 1 and 2) were grown simultaneously by MOCVD on two separate SI GaAs substrates 1 cm square, in the same reactor and under identical conditions. Subsequently, sample 1 was transferred in an inert ambient to another similar reactor where a $0.35 \mu\text{m}$ thick n-ZnSe epilayer was grown on top of it. After removing 2 mm square of ZnSe from each of the four corners for electrical contacts to the underlying n-GaAs epilayer using alloyed tin dots, the GaAs epilayer was found by the Van Der Pauw technique to be completely depleted, although the electron concentration of the n-GaAs epilayer of sample 2 was $9.0 \cdot 10^{14} \text{ cm}^{-3}$. Furthermore, on removing additional ZnSe so that a 2 mm wide strip of GaAs was fully exposed between two contacts on one side of the sample, this GaAs strip became conducting, although the conductivity across the diagonal was zero. This indicates that electron depletion occurs on the GaAs side of the interface contrary to popular expectations^{7,8}.

In addition, low T conductivity measurements of the n-ZnSe epilayer of sample 1 showed properties corresponding to a 2-D metallic system. Between 1.4 and 6 K the conduction is activated (Fig. 1), being given by

$$\sigma = 2.59 \cdot 10^{-4} \exp[-(107.7/T)^{1/2}]$$

which has been observed in quench-condensed metal films like Au and Cu⁹ and also Si inversion layers^{10,11}. Above 6 K the conduction goes over continuously to a

logarithmic dependence on T as shown in Fig. 2. The conductance has the well-known dependence :

$$\sigma(T) = \sigma(T_0) + \frac{\alpha P e^2}{\pi h} \ln(T/T_0)$$

where $\sigma(T_0) = 1.33 \cdot 10^{-5} \Omega^{-1}$, $T_0 = 18K$ and $\alpha P = 0.87$. The deviation in Fig. 2 at high T results from excitation to the conduction band from neutral donor impurities in the bulk ZnSe. The corresponding conductance is :

$$\sigma' = \sigma_c \exp[-(E_c - E_F)/K_B T]$$

where $\sigma_c = 2.28 \cdot 10^{-5} \Omega^{-1}$ and $E_c - E_F = 14.06$ meV, K_B being the Boltzmann constant. This energy is approximately half the shallow donor binding energy in ZnSe¹ as expected for a compensated crystal in this T range, where $N_D > n > N_A$. We note that $\sigma(T_0)$ is close to the minimum metallic value $e^2/\pi h = 1.23 \cdot 10^{-5} \Omega^{-1}$. This system, which differs essentially from the GaAs/GaAlAs heterostructure, has

Fig.1 $\ln[\sigma(T)]$ vs. $T^{-1/2}$ between 1.4 and 6 K

considerable disorder due to impurity compensation and interfacial non-uniformity, but does have similar transport properties to that observed in doping-modulated GaAs superlattices¹². Moreover, the n-ZnSe/n-GaAs heterostructure on a SI GaAs substrate with conducting ZnSe as gate has FET characteristics. Photoconductivity of the n-ZnSe layer grown on n-GaAs was measured at 7 K using below ZnSe band-gap illumination (6828 nm). A logarithmic decrease of resistivity with light intensity was obtained, and was inconclusive

due perhaps to electron excitation from deep electron-trap levels in the ZnSe.

In conclusion we have shown some evidence which indicates that for a n-ZnSe/n-GaAs heterostructure, electron accumulation occurs on the ZnSe side due presumably to the polarization change at the interface. Indeed, exploratory n-ZnSe/n-GaAs/n⁺-GaAs heterojunctions showed a 0.8 V photovoltage, with the GaAs side negative, consistent with GaAs depletion. The results are consistent with the self-consistent pseudo-potential of Ihm and Cohen¹³ for (100) ZnSe/GaAs interface. The conductance of the n-ZnSe decreased logarithmically with T going over to activated conduction at 6 K due to strong localization, a characteristic of a 2-D metallic system. Zn diffusion in GaAs does not appear to be a problem during the MOCVD growth, ZnSe being readily formed at the GaAs surface.

Fig.2 $\sigma(T)$ vs. $\ln(T/T_0)$ between 10 and 150 K

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