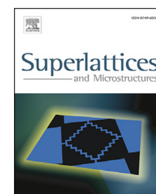
Superlattices and Microstructures 104 (2017) 156–161

Contents lists available at ScienceDirect

Superlattices and Microstructures

journal homepage: www.elsevier.com/locate/superlattices



Determination of mobility edge in presence of metal-to-insulator transition

M.A. Tito, Yu. A. Pusep*

São Carlos Institute of Physics, University of São Paulo, PO Box 369, 13560-970 São Carlos, SP, Brazil

A R T I C L E I N F O

Article history:
Received 21 December 2016
Accepted 28 December 2016
Available online 20 February 2017

Keywords:
Metal-to-insulator transition
Interface
Time-resolved photoluminescence

A B S T R A C T

Determination of mobility edge in presence of metal-to-insulator transition Recombination dynamics of excitons was studied in multiple narrow quantum well GaAs/AlGaAs heterostructures. Disorder generated by interface roughness considerably affects transport of the conduction band electrons and at appropriate quantum well width results in a metal-to insulator transition. Localization of the electrons was found to be responsible for the exciton recombination time measured in the vicinity of the metal-to-insulator transition. Measurement of the exciton recombination time as a function of the energy allowed for determination of the critical energy of the mobility edge attributed to the conduction band electrons. The mobility edge energy obtained in this way demonstrates intersection with the Fermi level energy at the critical disorder corresponding to the metal-to-insulator transition.

© 2017 Elsevier Ltd. All rights reserved.

1. Introduction

The mobility edge energy is the fundamental critical parameter of a three-dimensional localization theory, which separates the below lying localized states from the above high energy extended states [1,2]. Thus, the mobility edge defines the transition from insulator to metal state of matter: the charged carriers with the energy above the mobility edge contribute to the conductivity, while those with the energy below the mobility edge are localized. In spite of the more than forty years history of the mobility edge concept, its determination remains a challenge. According to a one-parameter scaling theory [3], the zero temperature conductivity varies with the energy E as,

$$\sigma(T=0) = (E - E_c)^{\mu} \tag{1}$$

where E_c is the mobility edge energy and μ is the critical exponent. First experimental determination of the mobility edge was performed by means of the electric transport measurements in two-dimensional Si inversion layers in Ref. [4]. However, a nature of the metal-to-insulator transition observed in two-dimensional electron systems is still under dispute. According to the scaling theory of localization, a metallic conduction is not expected in two dimensions. At present, it is believed that the metallic phase observed in two-dimensional systems is due to the interaction effects [5]. Therefore, nonexistence of a true Anderson metal-to-insulator transition in two dimensions is inconsistent with a mobility edge. Recently, a three-dimensional Anderson localization was demonstrated in ultracold spin-polarized Fermi atom gas [6,7] and in ultracold atoms of a Bose-

* Corresponding author.
E-mail address: pusep@ifsc.usp.br (Yu.A. Pusep).

http://dx.doi.org/10.1016/j.spmi.2016.12.060
0749-6036/© 2017 Elsevier Ltd. All rights reserved.

Einstein condensate [8], both set in a disordered potential created by speckle light field. Determination of the mobility edge energy was performed in such Bose-Einstein condensate in Ref. [9]. However, to the best of our knowledge, such experiments were not yet realized in three-dimensional electron systems.

In the present work we report on measurements of the mobility edge in a three-dimensional disordered system of Fermi electrons. Using the time-resolved photoluminescence (PL) technique we study the recombination time of the electrons photoexcited in disordered potential. The electrons residing below the mobility edge energy are localized and consequently, recombine with the holes during a longer time relative to the extended electrons above the mobility edge. The recombination time changes at the energy of the mobility edge which therefore, can be determined. It is worth mentioning, that spectroscopic measurements of the mobility edge energy comprise an important advantage as compared to electric transport measurements: the mobility edge is determined at a constant electron density which therefore, does not change a state of electron system.

2. Experimental details

The samples studied here were $(GaAs)_m(Al_{0.3}Ga_{0.7}As)_n$ superlattices (SLs) uniformly doped with Si, where m and n are the thicknesses of corresponding layers expressed in monolayers, ML. The total number of 30 periods was grown by molecular beam epitaxy on the (001) semi-insulating GaAs substrates. All the samples were doped with the same nominal concentration of Si, which forms the Fermi gas of the conductive electrons. The disordered potential required for the localization is given by the interface roughness always present in semiconductor heterostructures. The effect of the interface imperfections dominates the parallel transport in the short-period SLs, while it vanishes with the increasing quantum well width. Thus, the controlled variation of the quantum well thicknesses may cause the disorder induced metal-to-insulator transition predicted to occur due to interface roughness scattering in Ref. [10]. The roughness of the GaAs/AlGaAs interface is associated with smooth potential fluctuations which do not break uniformity of the electron density, while they generate necessary electron scattering. As shown in Ref. [11], a variation of the thickness of the GaAs wells m in the range 10–150 ML, while the thickness of the $Al_{0.3}Ga_{0.7}As$ barriers n is fixed at 6 ML, provides for the interface roughness disorder driven metal-to-insulator transition.

Transport measurements were performed using standard four probe low-frequency (5 Hz) lock-in technique in a pumped liquid He Oxford Instruments cryostat in the magnetic field directed perpendicular to the layers at the temperatures 1.6–15 K. The electric transport characteristics of the superlattices studied here are presented in Table 1. The low mobilities obtained in SLs with narrow quantum wells are related to the interface roughness scattering, which is the dominant mechanism in the GaAs/AlGaAs quantum wells with a well thickness smaller than 60 Å (about 20 ML) [12]. The zero-magnetic field resistance measured as a function of the temperature is shown in the inset to Fig. 1. Analysis of the transport properties of these SLs presented in details in Ref. [11] demonstrates that at sufficiently narrow quantum wells the interface roughness scattering is able to localize electrons. Activation type resistance corresponding to the insulating regime was found in the samples with quantum well widths $m = 10$ and 15 ML, while metallic conductivity was observed in the structures with $m = 30, 50, 150$ ML. In addition, the low-magnetic field negative magnetoresistance associated with the quantum interference effect was shown to change from positive to negative concavity when passing from metallic to insulating transport regime. As a result, the transition from a weak to strong localization regime was observed. According to these data, a complete localization of electrons was found in the SL with 10 ML quantum well width.

PL and time-resolved PL measurements were performed at the temperature 1.6 K. The samples were excited by a diode laser (Pico Quant - LDH-730) emitting at 470 nm in a continuous mode. The PL was collected by an Ocean Optics Inc. HR4000 high-resolution spectrometer. The same laser generated 70 ps pulses at the frequency 80 MHz for time-resolved PL measurements. The PL emission was dispersed by a SPEX500M spectrometer and the PL time delay was detected by a Hamamatsu H10330B-75 infrared photomultiplier tube.

3. Results and discussion

Both the electron states of the conduction and valence bands contribute to the optical interband transitions. Therefore, PL emission reflects features of the both bands. However, due to significant difference between the effective mass of the electrons and the heavy holes in GaAs, localization of the electrons in the conduction band takes place in a weaker disorder potential as compared to the heavy holes. This means that the same structural disorder results in perturbations of the

Table 1
Transport data obtained in $(GaAs)_m(Al_{0.3}Ga_{0.7}As)_6$ superlattices at $T = 1.6$ K.

m, ML	n_H, cm^{-3}	μ_H, $\frac{cm^2}{Vs}$
150	5.1×10^{17}	2513
50	8.3×10^{17}	2500
30	3.4×10^{17}	1027
15	7.1×10^{16}	446
10	1.0×10^{17}	64

Download English Version:

https://daneshyari.com/en/article/7940764

Download Persian Version:

https://daneshyari.com/article/7940764

Daneshyari.com