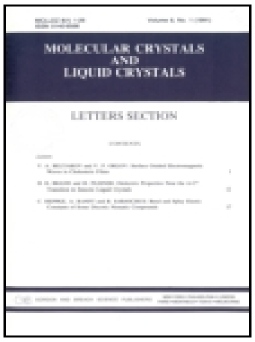

Molecular Crystals and Liquid Crystals

ISSN: 1542-1406 (Print) 1563-5287 (Online) Journal homepage: http://www.tandfonline.com/loi/gmcl20

Study of metal insulator transition: percolation-type in GaAs/AlGaAs 2D

Asmaa Chakhmane, Hassan Elidrissi & Abdelhamid Elkaaouachi

To cite this article: Asmaa Chakhmane, Hassan Elidrissi & Abdelhamid Elkaaouachi (2016) Study of metal insulator transition: percolation-type in GaAs/AlGaAs 2D, Molecular Crystals and Liquid Crystals, 627:1, 92-96, DOI: 10.1080/15421406.2015.1137136

To link to this article: http://dx.doi.org/10.1080/15421406.2015.1137136

Published online: 13 May 2016.

MOL. CRYST. LIQ. CRYST.
2016, VOL. 627, 92–96
http://dx.doi.org/10.1080/15421406.2015.1137136

Study of metal insulator transition: percolation-type in GaAs/AlGaAs 2D

Asmaa Chakhmane[a], Hassan Elidrissi[a], and Abdelhamid Elkaaouachi[b]

[a]Laboratory EEA&TI, Faculty of Sciences and Technology of Mohammedia, Mohammedia, Morocco; [b]Physics Department, Faculty of Sciences, University Ibn Zohr,Hay Dakhla, Agadir, Morocco

ABSTRACT
In this work the existence of a possible percolation transition in a dilute two dimensional hole gas in GaAs/AlGaAs within a parallel magnetic field at a fixed temperature T = 260mk is studied. Following the evolution of the electrical conductivity as a function of magnetic field at high carrier densities, we have showed the creation of a densitity inhomogeneity beyond the critical percolation leading to metallic side. These results were proved in the present article by studying the exponent characterizing the type of transition and the variation of the critical percolation densities, which are considered good indicators to observe the percolation transition. In this investigation, we have reanalyzed the data obtained by Kumar et al published in the reference [M. Kumar et al, Solid State Communications Vol. 135. pp. 57–61 (2005)].

KEYWORDS
2D GaAs hole gas; Percolation mechanism; Parallel magnetic field; Metal insulator Transition

1. Introduction

Two dimensional 2D hole systems at very low temperatures present a database of research to study the physical effects of Coulomb interactions [1] in the presence of disorder. For years, several studies have been made on the dependence of the temperature of resistivity describing the Metal Insulator Transition in semiconductors for low carrier's densities [2–5]. The first 2D-MIT was observed in Silicon Metal Oxide Semiconductor Field Effect Transistors (Si-MOSFETs) [6]. Several concepts have been proposed to explain this finding such as the quantum phase transition that was challenged by the percolation transition at T = 0, as well the impact of strong density inhomogeneity near the critical density on the metallic behavior in 2D [7–10].

To describe the transition of the resistivity from metallic behavior to an apparent low density insulating behavior, Efros [11] and Nixon [12] suggested a model of percolation transition in 2D gas. The percolation theory is used in many fields to model the structure or the information transmission in disordered environment such as the electrical conductivity of a metal grid (percolation of links) or a mixture of insulating particles and conductive particles (percolation of sites). The problem with the disorder involves the notion valleys and hills of the potential which are randomly distributed in the flow surface. The charge carriers are fended in the hills and accumulate in the valleys [13]. With

CONTACT Asmaa Chakhmane asmaa.chakhmane@gmail.com Laboratory EEA & TI, Faculty of Sciences and Technology of Mohammedia, Mohammedia, Morocco
Color versions of one or more of the figures in the article can be found online atwww.tandfonline.com/gmcl.

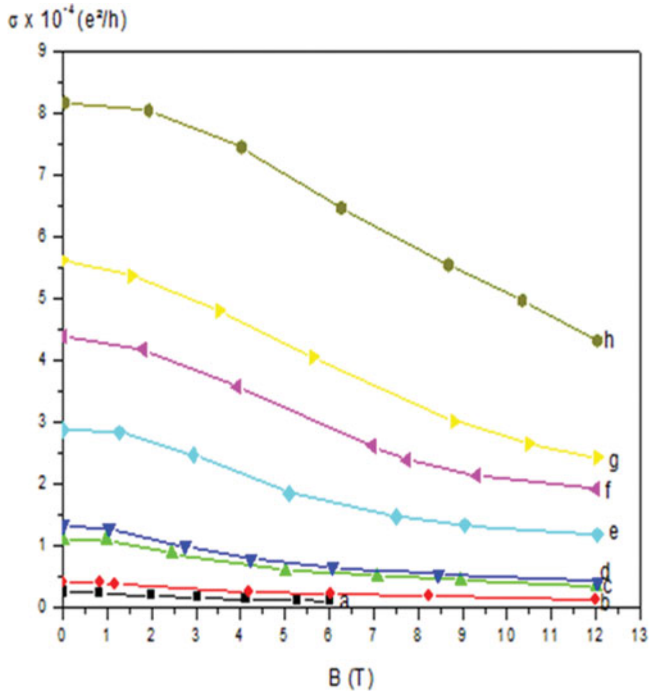

Figure 1. The conductivity dependence of the magnetic field for several hole densities in unit of x10^{10}cm^{-2}. a: 2.9; b: 3.1;c: 3.4; d: 3.7; e: 4.3; f :4.5 ;g :6.1 ; h: 7.4.

increasing carrier density, the accumulation is also done on the hills, so the gas is gradually becoming able to overcome the disorder potential, the electrical contact is ensured between the continuous conductive paths and thus it will produce the transition metal phase. Several models have been proposed to describe the percolation MIT (i.e., Meir [14], Shi *et al* [15], Tracy *et al* [16] and Das Sarma *et al* [17]) which predict that doping impurities revealed the inhomogeneities of densities created by a long-range potential in the 2D gas.

In this paper, we try to prove the existence of a percolation transition by studying the behavior of the conductivity with a parallel magnetic field applied in 2D p-GaAs system in a high mobility and at very low temperature.

2. Results and discussion

MIT is usually brought in heterostructures by varying of an external element (i.e., temperature, magnetic field, impurities) this can act on transport phenomena, carrier-carrier interactions, weak localization, which can create a transition percolation. Different to studies done in this context (the effect of the variation of temperature on the formation of the percolation transition), in this work we will study the conductivity behavior as a function of parallel magnetic field from 0 T to 12 T with carrier densities from 2.9 to 6.1 × 10^{10} cm^{-2} at a fixed temperature T = 260 mK.

We have reanalyzed the data obtained by Kumar *et al.* published in reference [18]. The magnetic field dependence of the electrical conductivity for various hole densities is shown in figure 1.

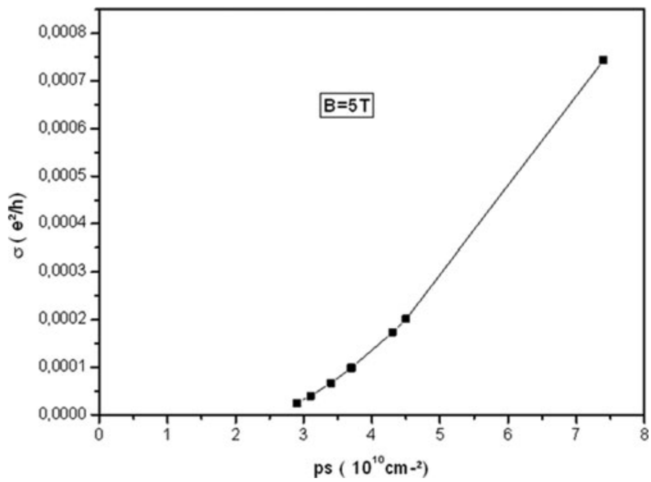

Figure 2. Electrical conductivity σ versus hole densities ps at a fixed magnetic field B = 5 T. The line represents the adjustment results.

This figure shows that there is a decrease in conductivity by increasing the magnetic field and the hole density. Below a critical density equal to 3.1 × 10^{10} cm^{-2}, conductivity is almost constant for all of the magnetic field range, it may be noted that these low densities does not produce a mobility of charge carriers in the gas.

In the percolation model, the electrical conductivity $\sigma(p_s)$close to the threshold density is expressed by

$$\sigma\,(p_s) = A\left(p_s - p_{sc}{}^{*}\right)^{\delta} \tag{1}$$

where A is a constant of proportionality, psc* is critical percolation threshold density. We note that this can be different than the critical densities obtained by the thermal coefficient of resistivity (TCR), δ is an exponent characterizing the type of transition. In the case where the percolation is governed by percolation mechanism, $\delta = 4/3$ for 2D and $\delta = 2$ for 3D [19].

To determinate the value of $p_{sc}{}^{*}$, we adjusted the data using Eq. (1), we plotted the variation of electrical conductivity of hole densities at a fixed value of magnetic field B = 5 T in figure 2. We observed that the conductivity increases by increasing p_s and goes to zero at $p_{sc}{}^{*} = 2.35 \times 10^{10}$ cm-². For other magnetic field values from 0 T to 12 T, we adopt the same reasoning to identify the parameters A, δ and $p_{sc}{}^{*}$.

In figure 3 we plotted the variation of the exponent δ as a function of the applied magnetic field for this sample. It may be noted that in this figure was determined both magnetic field range. For low densities and for magnetic field between 0 T and 5 T, there was obtained a value of the exponent δ which varies between 1.73 and 1.55. On the other side, for higher densities and from 6 T to 12 T, the value of the exponent δ is nearly equal to 1.33. Both findings are consistent with the percolation mechanism [19].

In figure 4, we presented the variation of the critical percolation threshold density as a function of the parallel magnetic field. We clearly saw a peak at B = 3 T, below which a nearly constant density is obtained. In this range we cannot determine the metal and insulating phase. Beyond this value and from the critical percolation threshold density $p_{sc}{}^{*} = 2.35 \times 1010$ cm-², a transition percolation occurs, which is affirmed by the previous result of the exponent δ in the same range.

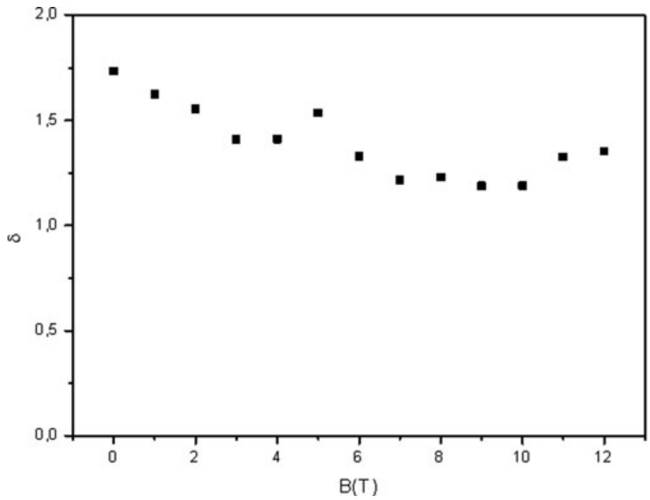

Figure 3. the exponent δ versus magnetic field from 0 T to 12 T.

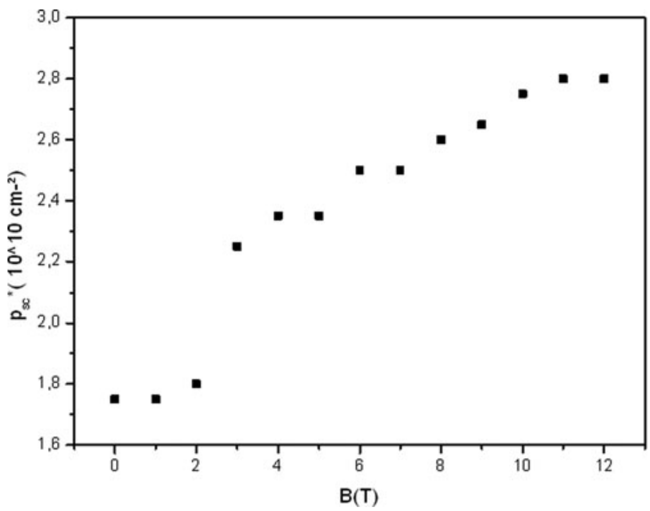

Figure 4. the critical percolation threshold density $p_{sc}*$ versus B(T); The average critical value of the percolation is approximately equal to 2.37×10^{10} cm^{-2}.

Combining the two results, for high values of magnetic field, the density of doped impurities should be higher than the critical value that is equal to 2.35×1010 cm-², which generates a high mobility of the charge carriers. Thus, it results a metallic behavior. This effect consists to homogenize the density of the gas holes 2D and hence occurs the percolation transition [13]. This mechanism has been observed in a few 2D systems [20–23] as a clear challenge to the quantum phase transition hypothesis proposed by other authors [7, 8].

3. Conclusions

In conclusion, we demonstrate and explain the appearance of the percolation transition in 2D p-GaAs gas, by adopting a similar study in investigations made on other samples, but by acting on the magnetic field effect and the hole density. The temperature in our study remains constant throughout this analysis. The impact of these two factors resides paramount for the creation of interactions charge carriers and long-range effects due to random impurities. For high densities (at beyond the critical value) the gas is able to screen the potential disorder which includes a metallic behavior.

Acknowledgments

We gratefully thank M. Mukesh Kumar, M. Giorgio Biasiol (biasiol@iom.cnr.it) et al. [18] for allowing us to use their experimental results on dilute 2D GaAs hole system in our investigation.

References

[1] Letureq, R., L'Hote, D., Tourbot, R., Mellor, C. J., & Henini, M. (2003). *Phys. Rev. Lett.*, *90*, 076402.
[2] Noh, J. P., Shimogishi, F., Idutsu, Y., & Otsuka, N. (2004). *Phys. Rev. B*, *69*, 04532 1.
[3] Manfra, M. J., Hwang, E. H., Das Sarma, S., Pfeiffer, L. N., West, K. W., & Sergent, A. M. (2007). *Phys. Rev. Lett.*, *99*, 236402.
[4] Das Sarma, S., Lilly, M. P., Hwang, E. H., Pfeiffer, L. N., West, K. W., et al. (2005). *Phys. Rev. Lett.*, *94*, 136401.
[5] Abrahams, E., Anderson, P. W., Licciardello, D. C., & Ramakrishnan, T. V. (1979). *Phys. Rev. Lett.*, *42*, 673.
[6] Kravchenko, S. V., Kravchenko, G. V., Furneaux, J. E., Pudalov, V. M., & D'Iorio, M. (1994). *Phys. Rev. B*, *50*, 8039.
[7] Kravchenko, S. V. et al. (1996). *Phys. Rev. B*, *51*, 7038.
[8] Abrahams, E., Kravchenko, S. V., & Sarachik, M. P. (2001). *Rev. Mod. Phys.*, *73*, 251.
[9] Ilani, S., Yacoby, A., Mahalu, D., & Shtrikman, H. (2000). *Phys. Rev. Lett.*, *84*, 3133.
[10] Shi, J. & Xie, X. C. (2002). *Phys. Rev. Lett.*, *88*, 086401.
[11] Efros, A. L. (1989). *Solid State Comm.*, *70*, 253.
[12] Nixon, J. A., & Davies, J. H. (1999). *Phys. Rev. B*, *41*, 7929.
[13] Shi, J., He, S., Xie, X. C., Shi, J. & Xie, X. C. (2002). *Phys. Rev. Lett.*, *88*, 086401.
[14] Meir, Y., Shi, J. & Xie, X. C. (1999). *Phys. Rev. Lett.*, *88*, 83, 3506.
[15] Shi, J., He, S., & Xie, X. C. (1999). Cond-mat/9904393.
[16] Tracy, L. A., Eisenstein, J. P., Lilly, M. P., Pfeiffer, L. N., West, K. W. (2006). *Solid State Comm.*, *137*, 150.
[17] Das Sarma, S., & Hwang, E. H. (2005). *Solid State Comm.*, *235*, 579.
[18] Kumar, M., Moria, G., Capotondia, F., Biasiol, G. & Sorba, L. (2005). *Solid State Comm.*, *135*, 57–61
[19] Stauffer, D., Aharaony, A. (1992). *Introduction to Percolation Theory*, Taylor & Francis, London, Eds. Shklovskii, B. I., Efros, A. L., *Electronic Properties of Doped Semiconductors*, Springer-Verlag, New York, pp. 984.
[20] Tracy, L. A., Hwang, E. H., Eng, K., Ten Eyck, G. A., Nordberg, E. P., et al. (2009). *Phys. Rev. B*, *79*, 235307.
[21] Abdalla, S. (2011). *Canadian J. Sci. Eng. Math.*, *2*, 1.
[22] Lilly, M. P., Reno, J. L., Simmons, J. A., Spielman, I. B., Eisenstein, J. P., et al. (2003). *Phys. Rev. Lett.*, *90*, 056806.
[23] Fogler, M. M. (2004). *Phys. Rev. B*, *69*, 121409.