Vol. 79 (1991) *ACTA PHYSICA POLONICA A* No 2–3

Proc. XIX International School of Semiconducting Compounds, Jaszowiec 1990

CONDUCTIVITY NEAR THE METAL-TO-INSULATOR TRANSITION IN $Cd_{1-x}Mn_xSe$:Sc*

P. Głód, M. Sawicki, A. Lenard, T. Dietl and W. Plesiewicz

Institute of Physics, Polish Academy of Sciences, Al. Lotników 32/46, 02-668 Warszawa, Poland

(Received August 8, 1990)

Earlier studies of transition metal impurities in II–VI compounds suggest that Sc acts as a resonant donor. We performed Hall effect and conductivity measurements of CdSe:Sc and $Cd_{0.95}Mn_{0.05}Se$:Sc. The results, particularly the critical concentration of the metal-to-insulator transition, turned out to be similar to those obtained previously for $Cd_{1-x}Mn_xSe$ doped with hydrogenic-like impurities, such as In and Ga. Therefore, if the ground state of Sc impurity is indeed located above the bottom of the conduction band, our data demonstrate that the metal-to-insulator transition is primarily driven by the scattering, i.e. it corresponds to the Anderson localization.

PACS numbers: 71.30.+h, 71.55.Jv

It is generally accepted that the formation of local states by impurities with open magnetic shells cannot be described within the one-electron effective mass approximation [1]. For instance, Mn in CdSe gives rise to a donor state which lies about 3 eV below the top of the valence band, while the Sc donor level is expected to be degenerate with the conduction band [2]. If indeed the lowest donor state of Sc is located above the bottom of the conduction band, $Cd_{1-x}Mn_xSe$:Sc offers a rather unique opportunity to shed new light on the nature of electron localization in doped semiconductors. This is because the metal-to-insulator transition may be driven by two distinct mechanisms [3]:

(i) quantum localization of the Fermi liquid induced by scattering (Anderson localization);

*This work was supported by the Institute for Low Temperature and Structural Research, Polish Academy of Sciences.

(ii) conversion of the Fermi-liquid quasiparticles into local electron magnetic moments (Mott–Hubbard transition).

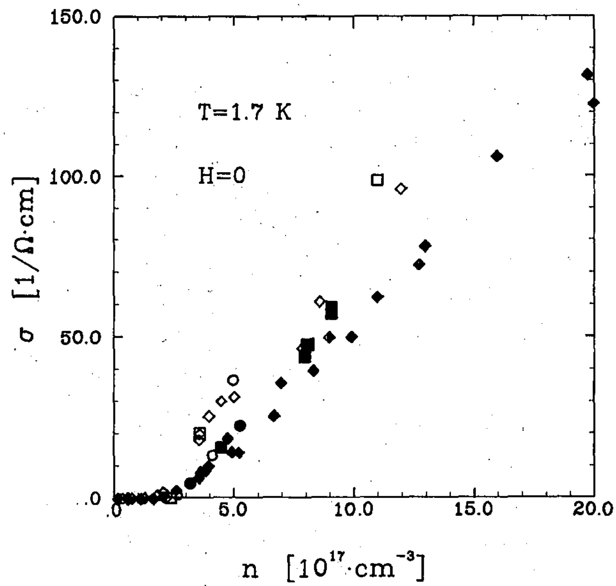

Fig.1. Conductivity as a function of electron concentration for n-CdSe and n-$Cd_{0.95}Mn_{0.05}Se$ (open and solid symbols, respectively): squares — CdSe:Sc, $Cd_{0.95}Mn_{0.05}Se$:Sc (this work); rhombs — CdSe:In, $Cd_{0.95}Mn_{0.05}Se$:In [4–6]; circles — CdSe [7]; $Cd_{0.95}Mn_{0.05}Se$:Ga [8].

In the case when the potential of a single impurity has no bound states (as is probably the case of Sc in CdSe), the localization by the Mott–Hubbard mechanism should be inoperative. At the same time Anderson's metal-to-insulator transition may occur as a result of the collective action of many scattering centers on the electron motion.

The CdSe:Sc and $Cd_{0.95}Mn_{0.05}Se$:Sc crystals were grown by the Bridgman method, with the concentration of Sc ranging from 5×10^{17} cm^{-3} to 10^{18} cm^{-3}. The electrical contacts to the Hall-bar samples were prepared by soldering indium in helium atmosphere. The measurements were performed using either a.c. or d.c. techniques.

The conductivity of our samples at $T = 1.7$ K as a function of electron concentration deduced from Hall effect data at 300 K is shown in Fig. 1 in comparison with previous results for CdSe and $Cd_{0.95}Mn_{0.05}Se$ doped with hydrogenic-like donors. We see, that Sc doping produces electrons and therefore Sc acts indeed as a donor whose energy level is either resonant with the conduction band or very shallow. Furthermore, the conductivity of $Cd_{1-x}Mn_xSe$:Sc and, in particular, the critical concentration of the metal-to-insulator transition are similar to those of

$Cd_{1-x}Mn_xSe$ containing hydrogenic-like dopants. Also, no significant difference between $Cd_{1-x}Mn_xSe$:Sc and $Cd_{1-x}Mn_xSe$:In was noted when studying the magnetoresistance and the temperature dependence of conductivity, as shown in Fig. 2.

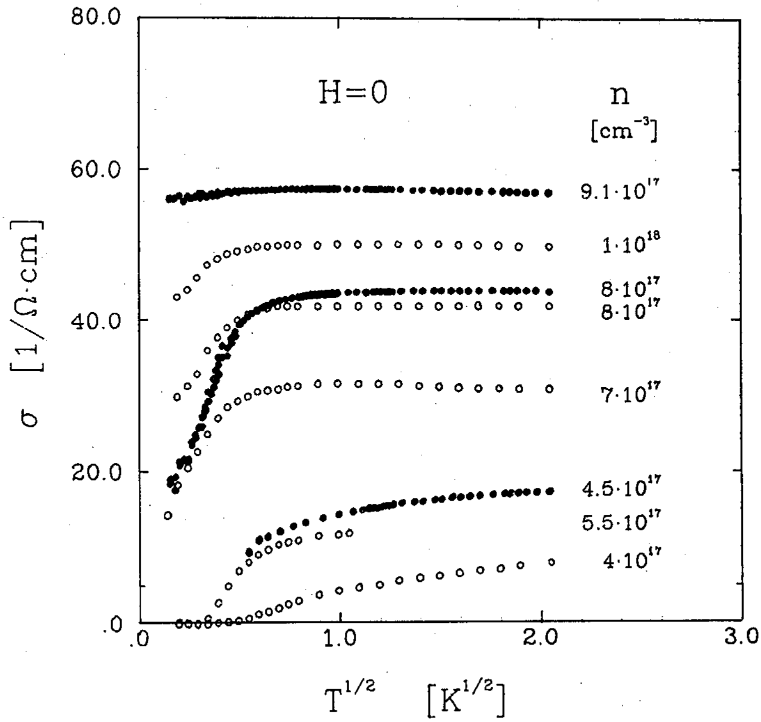

Fig. 2. Conductivity as a function of temperature for n-$Cd_{0.95}Mn_{0.05}Se$: solid symbols — $Cd_{0.95}Mn_{0.05}Se$:Sc (this work); open symbols — $Cd_{0.95}Mn_{0.05}Se$:In [6].

Our results provide therefore a new indication that localization in doped semiconductors is caused primarily by the Anderson mechanism. Further work is in progress to substantiate this conclusion and, in particular, to find out whether Sc creates only the resonant states, as well as to elucidate the role of native defects and impurities in $Cd_{1-x}Mn_xSe$:Sc.

References

[1] see, e.g., P. Vogl, J.M. Baranowski, *Acta Phys. Pol.* **A67**, 133 (1985);
A. Zunger, in *Solid State Physics*, Vol 39, eds. F. Seitz, D. Turnbull, Academic Press, New York 1986, p. 275;
V.I. Sokolov, *Fiz. Tverd. Tela* **29**, 1848 (1987);
Sov. Phys.- Solid State **29**, 1061 (1987);

J.M. Langer, C. Delerue, M. Lannoo, H. Heinrich, *Phys. Rev. B* **38**, 7723 (1988).

[2] J.M. Baranowski, J.M. Langer, *Phys. Status Solidi B* **48**, 863 (1971).

[3] see, e.g. *Anderson Localization,* eds. T. Ando, H. Fukuyama, Springer, Berlin 1988;
Electron–Electron Interactions in Disordered Systems, eds. A.L. Efros, M. Pollak, North-Holland, Amsterdam 1985;
T. Dietl, *Acta Phys. Pol.* **A73**, 793 (1988).

[4] M. Sawicki, T. Dietl, J. Kossut, J. Igalson, T. Wojtowicz, W. Plesiewicz, *Phys. Rev. Lett.* **56**, 508 (1986).

[5] T. Dietl, L. Świerkowski, J. Jaroszyński, M. Sawicki, T. Wojtowicz, *Phys. Scr.* **T14**, 29 (1986).

[6] T. Dietl, M. Sawicki, T. Wojtowicz, J. Jaroszyński, W. Plesiewicz, L. Świerkowski, J. Kossut, in *Anderson Localization,* eds. T. Ando, H. Fukuyama, Springer, Berlin 1988, p. 58.

[7] D.M. Finlayson, J. Irvine, L.S. Peterkin, *Philos. Mag. B* **39**, 253 (1979).

[8] Y. Shapira, N.F. Oliveira, D.H. Ridgley, R. Kershaw, K. Dwight, A. Wold, *Phys. Rev. B* **34**, 4187 (1986)