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ELECTRICAL CONDUCTIVITY BEHAVIOUR OF Gd DOPED EuO UNDER HYDROSTATIC PRESSURE

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Résumé.- Des monocristaux de EuO dopé au Gd ont été élaborés avec une concentration initiale en Gd de 1,5%. Le paramètre de réseau a été déterminé aux rayons X et est plus petit que celui de l’EuO pur. Des mesures de résistivité ont été faites jusqu’à 5 kbar de 50 K à 200 K. La concentration des porteurs a été déterminée à haute et basse température par des mesures d’effet Hall. La température de Curie a été déterminée par des mesures de magnétisation.

Les points importants qui ressortent de ce travail sont que :

i) la résistivité décroît sous pression tandis qu’elle augmente sur les échantillons d’EuO dopé à l’Eu;

ii) le pic de résistivité est déplacé avec la pression vers les hautes températures à raison de 0,8 K/kbar tandis que le point d’inflexion de la Courbe ρ(T) est déplacé à raison de 0,7 K/kbar. Le coefficient de pression négatif de la résistivité mesuré sur cet échantillon a été attribué à un effet de mélange des bandes 5d et 6s ; ainsi les variations de résistivité sous pression sont dues à des variations de mobilité car l’échantillon reste dégénéré à haute et basse température.

Abstract.- Single crystals of Gd doped EuO have been grown with an initial Gd concentration of 1.5%. The lattice parameter has been determined by X-ray analysis and is smaller that of pure EuO. Measurements of resistivity under hydrostatic pressure have been performed up to 5 Kbar in the temperature range 50 K - 200 K. The carrier concentration has been determined at high and low temperature by Hall effect measurements. The Curie temperature has been determined by magnetization measurements.

The main points of interest of this work are : i) the resistivity decreases under pressure while it increases in samples of Eu doped EuO ;

ii) the resistivity peak is shifted by pressure towards high temperature at a rate of 0.8 K/kbar while the inflexion point of the ρ-vs-T curve is shifted at a rate of 0.7 K/kbar. The negative pressure coefficient of resistivity measured for this sample has been explained by the mixing of 6s and 5d bands ; so that the variations of resistivity under pressure are due to mobility variations because the sample remains degenerated at high and low temperature.

1. Introduction.- In two preceding papers we investigated the resistivity behaviour of Eu rich EuO under hydrostatic /1/ and uniaxial /2/ pressure. The aim of the present work is to study the effect of an hydrostatic pressure on the resistivity of EuO samples doped with 1.5% of gadolinium.

The important difference between Eu rich and Gd doped crystals is that the first ones are oxygen deficient and the second ones are made up with an Eu + Gd composition which corresponds to stoichiometry.

The experimental results show a new fact : for Gd doped EuO, the pressure coefficient of resistivity is negative in the whole range 50 K - 300 K while it is positive in the paramagnetic phase (T>80K) for Eu rich EuO. We attempt to give an explanation for this difference.

2. Experimental results.- 1) The lattice parameter has been determined by a Debye-Scherrer diagram. The results are : for Eu rich EuO a = 5.143 Å ; for Gd doped EuO a = 5.137 Å. The substitution of Eu\(^{++}\) ions by Gd\(^{+++}\) diminishes the lattice parameter by a factor of 1.2%/\(\cdot\)a.

ii) A Curie temperature of about 70 K for Gd doped samples, has been determined by means of a vibrating sample magnetometer.

iii) The resistivity of Gd doped EuO has been measured under hydrostatic pressure up to 5 kbars in the temperature range 50K - 300K. The figure 1 shows the resistance curves for different pressures around T\(_C\) (50 - 180 K). At all temperatures the resistivity is decreased exponentially with pressure which allows us to define a pressure coefficient of resistivity \(\beta = \frac{d\ln\rho}{dP}\) which is plotted versus temperature in figure 2.
Fig. 1 Resistance versus temperature at different pressures.

For comparison, we have plotted the values of β for Eu rich EuO, in figure 3.

Fig. 2 EuO doped EuO

dotted line : experimental pressure coefficient of resistivity
\[ \beta = \frac{d \ln \rho}{dP} \]
versus temperature
full line : calculated magnetic dependent part of the pressure coefficient of resistivity
\[ \beta_m = \frac{d \ln \rho}{dT} \cdot \frac{dT_c}{dP} \]

3 Discussion.- The curve β (T) exhibits a minimum around 50 K, and a maximum around 120 K. This behaviour can be imputed to magnetic interactions. When pressure is applied, such magnetic interactions give to the following contribution:

\[ \beta_m = \frac{d \ln \rho}{dT_c} \cdot \frac{dT_c}{dP} \]

which is superposed on the pressure dependence of the resistivity with the lattice compressibility:

\[ \beta_m = \frac{d \ln \rho}{dP} \cdot \frac{d}{dT_c} \]
lattice

so, at all temperatures, we can write

\[ \beta = \beta_m + \beta_m \]

At low temperatures, when pressure is applied, the resistivity peak is shifted towards higher temperatures. It has been shown that for Eu rich EuO, this results from the shift of Tc by pressure. In the case of Gd doped samples, the peak is not so well defined and we have computed the second derivative \( \frac{d^2 \rho}{dT^2} \) of the \( \rho - v = T \) curve. The temperatures for which \( \frac{d^2 \rho}{dT^2} \) is zero, which correspond to Tc /3,4/ are
increased by pressure at a rate of 0.7 K/kbar which is in agreement with the shift of the resistivity peak. Then it is quite sure that around $T_c$, the resistivity is changed by the effect of pressure on magnetic interactions. We can then consider that the variations of $\beta_T$ with $T$ are negligible with respect to these of $\beta_m$:

$$\beta_m = -\frac{d \ln \rho}{d T} \cdot \frac{dT_c}{dP}$$

since $\rho$ only depends on $(T-T_c)$. There is no significant difference between Eu rich EuO and Gd doped EuO in this range of temperatures.

At high temperatures, on the contrary, $\beta_m$ vanishes and $\beta = \beta_T$. The experimental values is $-0.12 \times 10^{23}$ bar$^{-1}$ and remains constant. The sign of $\beta$ in this Gd doped EuO sample is thus negative although it is positive in Eu rich EuO. When $\text{Eu}^{++}$ ions are substituted by $\text{Gd}^{++}$ ones, the lattice parameter is decreased from 5.143 Å to 5.137 Å as mentioned above and it results that crystal field splittings of the 6$s$ - 5$d$ levels are increased /5/, so the mixing persists. The sample remains degenerated at all pressures and the carrier concentration is not changed. Thus the only parameter which can be pressure dependent is the mobility.

In the case of Eu rich EuO (1) we showed that the positive pressure coefficient is essentially due to a transfer from 6$s$ band to 5$d$ band with pressure assuming that they were shifted without deformation $d\nu_{1,2} = 0$).

Faking into account the deformation we obtain

$$\left(\frac{d \ln \rho}{dP}\right)_{\text{def}=0} = -|e| \left[\nu_1 \frac{dn_{1}}{dP} + \nu_2 \frac{dn_{2}}{dP}\right]$$

$$\text{with} \left(\frac{d \ln \rho}{dP}\right)_{\text{def}=0} = -|e| \left[\nu_1 \frac{dn_{1}}{dP} + \nu_2 \frac{dn_{2}}{dP}\right]$$

is the positive term, without deformation /2/. $e$ is the charge of electron.

When pressure is applied, the 6$s$,5$d$ band widths $W_{1,2}$ are increased due to the increase of the overlap of wave function, so that the effective masses are decreased $(m_{1,2} \propto W_{1,2}^{-1/2})$ and the mobilities are increased $(\mu_{1,2} \propto m_{1,2}^{1/2})$. We obtain $d\nu_{1,2} > 0$ and the second term in equation /1/ gives a negative contribution.

So, with a free carrier concentration of about $10^{20}$ cm$^{-3}$ in Gd doped sample the effect of the second term will be more important and we obtain a negative value in Gd doped EuO and a positive value of $\beta$ was obtained in Eu rich EuO.

4. Conclusion.- The study of transport properties under hydrostatic pressure as a function of temperature gives new information on conductivity processes in EuO.

For Gd doped EuO with a carrier concentration of about $10^{20}$ cm$^{-3}$ the pressure coefficient of resistivity is negative at all temperatures. It can be defined as the sum of two terms: $\beta_T + \beta_m$. The first one corresponds to the change in mobility as a result of pressure effect on the effective masses of 5$d$ and 6$s$ bands. The second one corresponds to the increase of the Curie temperature as a result of pressure effect on magnetic interactions. Eu rich EuO /1/ exhibits the same behaviour but the main part of resistivity changes are due to the transfer of electrons from 6$s$ band (high mobility) to 5$d$ band (low mobility) with pressure. This process is more important than that of effective mass and leads, in the paramagnetic phase, to a positive value of $\beta$. The high electron concentration induced by gadolinium increases the effect of band deformation and gives a negative value to $\beta$.

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References


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