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# INVESTIGATION OF THE PbTe-EuTe SYSTEM BY THIN-FILM TECHNIQUES

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**Résumé.** — Le système ternaire PbTe-EuTe a été exploré sur des couches minces obtenues par l'évaporation simultanée du composé PbTe et des éléments Eu et Te sur support amorphe ou sur NaCl. Les différentes compositions ont été obtenues par la variation de l'intensité relative des flux de vapeur. On constate dans tout le domaine de composition PbTe-EuTe, l'existence de solutions solides cristallisant dans la structure du sel gemme. Des mesures optiques ont été effectuées sur des couches monocristallines, ainsi que des mesures électriques.

Par ailleurs, PbTe a été formé par co-évaporation des éléments. Des couches de type *p* de très grande perfection cristalline ont été obtenues sur NaCl. Les mesures électriques et optiques effectuées montrent que ces couches ont les propriétés du matériau massif, et particulièrement une pureté très élevée.

**Abstract.** — The ternary PbTe-EuTe system has been studied on thin films which were obtained by simultaneous evaporation of PbTe and elemental Eu and Te on amorphous or NaCl substrates.

Different compositions were obtained by varying the relative intensity of the vapour flux. Over all the composition range of PbTe-EuTe, solid solutions are present, which crystallize in the rock-salt structure. Optical and electrical measurements were made on monocristalline layers.

Besides, PbTe was grown by co-evaporation of the elements. *p*-type films on NaCl exhibit very high crystalline perfection. Electrical and optical measurements show that these films have properties of bulk material and particularly a very high purity.

Compared to Si or Ge, II-VI or IV-VI compounds offer a better possibility of forming solid solutions with transition metal compounds. As it has been shown in the case of GeTe-MnTe alloys [1] and SnTe-MnTe alloys [2], magnetic interactions between Mn atoms do occur in these systems.

In this perspective we find it interesting to explore new systems which could offer further possibilities. Europium compounds, especially, the chalcogenides are of considerable interest because of their simple NaCl structure, like PbTe and because  $\text{Eu}^{++}$  has a half filled 4 - *f* shell.

Thin-film techniques which are very valuable in the preparation of ternary systems, were found to be very useful in the case of PbTe-EuTe alloys. The technique of co-evaporation under a vacuum of  $10^{-6}$  torr was adopted. For the preparation of PbTe, Pb and Te were co-evaporated and for EuTe, Eu and Te were co-evaporated. For all alloy compositions, PbTe compound, Eu and Te were co-evaporated.

We have an apparatus in which a large number of preparations of different compositions can be obtained in a single experiment. Substrates of borosilicate glass and NaCl were used.

Figure 1 shows lattice constants of our samples obtained by X-ray techniques. We see that values of the lattice constants are obtained in the whole interval separating PbTe and EuTe. In these preparations no foreign phase is detectable. We conclude that solid solutions exist all over the interval. Lattice parameter values of PbTe and EuTe films differ from those of

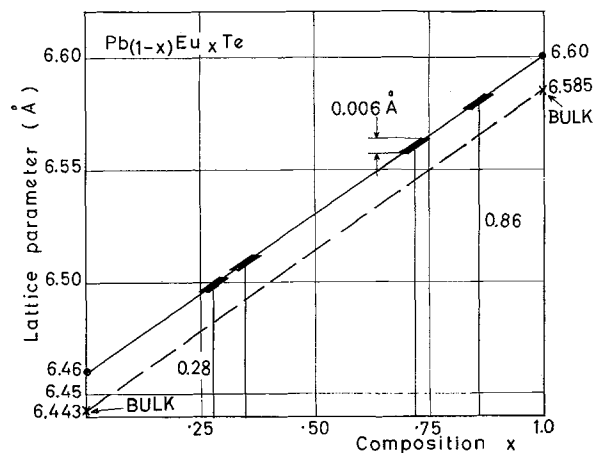


FIG. 1.

the bulk material. If we assume Vegard's law to hold, then X-axis gives the composition.

Figure 2 shows the energy dependence of the absorption coefficient of different samples. Vertical lines are the values of the bandgap obtained from the further assumption of linear variation of the value of the bandgap with the composition  $x$ . The bandgap values of PbTe and EuTe are obtained from our results as well as from [3] and [4] respectively. The long wavelength absorption front seems to fall in the neighbourhood of the vertical line. Thus our two assumptions are valid.

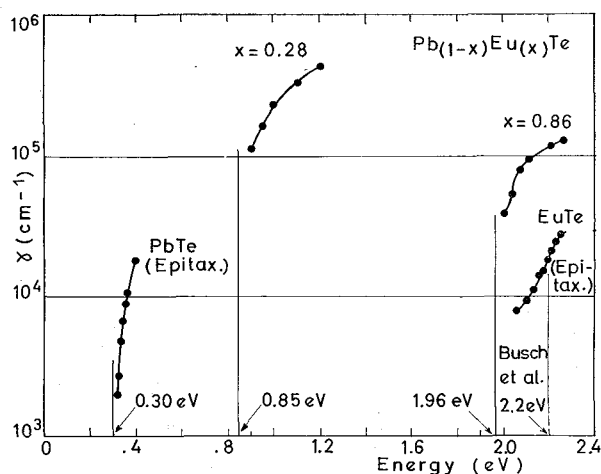


FIG. 2.

Figure 3 represents the dispersion of the index of refraction of these samples calculated from the interference pattern observed in reflection. The dispersion of  $n$  for  $x = 0.28$  is shown to have a break at 0.85 eV, the value obtained from the two assumptions. The longwavelength value of  $n$  for  $x = 0.86$  is shown to be constant upto 1.8 eV. We were unable to follow the dispersion in the vicinity of the assumed value of

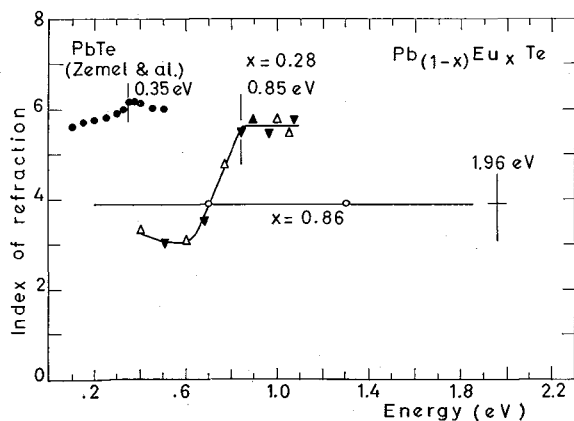


FIG. 3.

the gap. The determination of  $n$  for EuTe is still underway.

Figure 4 represents the dispersion of  $n$  for a co-evaporated PbTe film on NaCl. Our results are in good agreement with those of J. N. Zemel [5] although the thickness of this film, 2.6 micron, did not allow us to obtain values on the short wavelength side.

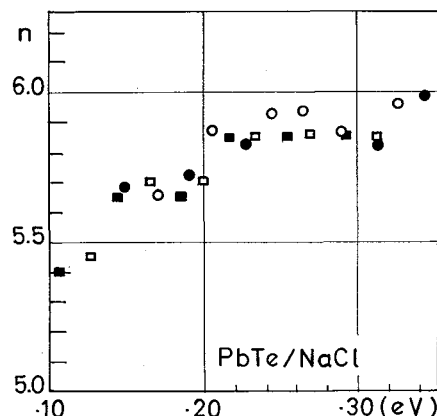


FIG. 4.

Figure 5 represents the electrical characteristics of the same film which is  $p$ -type. The carrier concen-

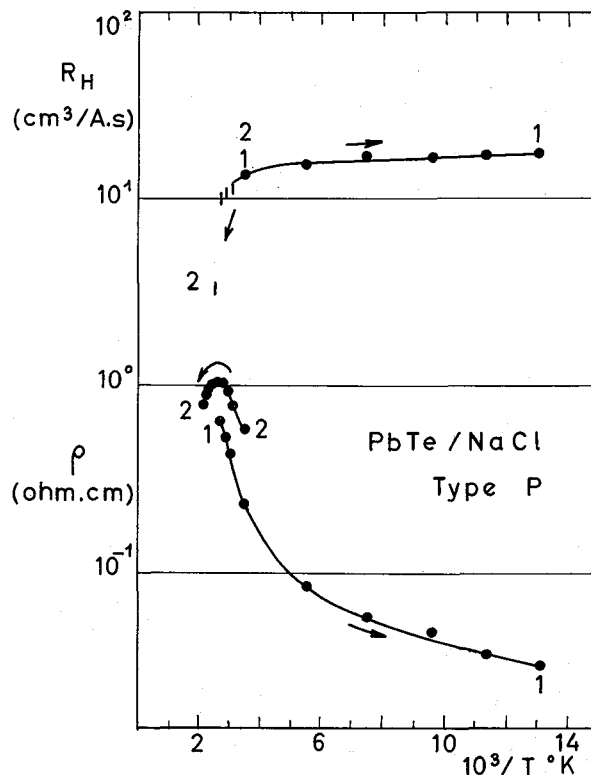


FIG. 5.

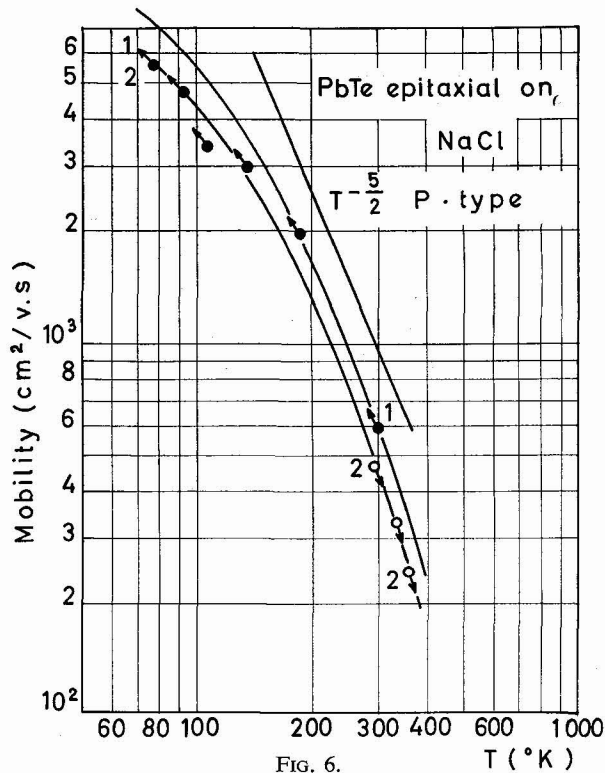


FIG. 6.

tration is  $3.5 \times 10^{17} \text{ cm}^{-3}$  at  $77^\circ\text{K}$ . We notice that at low temperature, damage produced to the film due to strain increases its resistivity. Figure 6 represents the temperature variation of Hall mobility. The behaviour between  $200^\circ\text{K}$  and  $300^\circ\text{K}$  is in good accord with the observed bulk behaviour,  $T^{-5/2}$ , in this temperature range. But for the low temperature damage, mobilities should have been higher in the low temperature range. In thinner films deposited on borosilicate glass substrates very low carrier concentrations typically below  $10^{16} \text{ cm}^{-3}$  were systematically obtained. This behaviour is not understood by us. As previously observed by others, mobilities of our PbTe films on glass have lower values than those of epitaxial films, with dominant grain boundary scattering.

Structure information was obtained with the aid of the Electron Microscope [6]. Figure 7 is an electron diffraction diagram of a 60 % EuTe film epitaxied on NaCl, figure 8 is an electron micrograph of the same sample showing clustering of small defects and figure 9

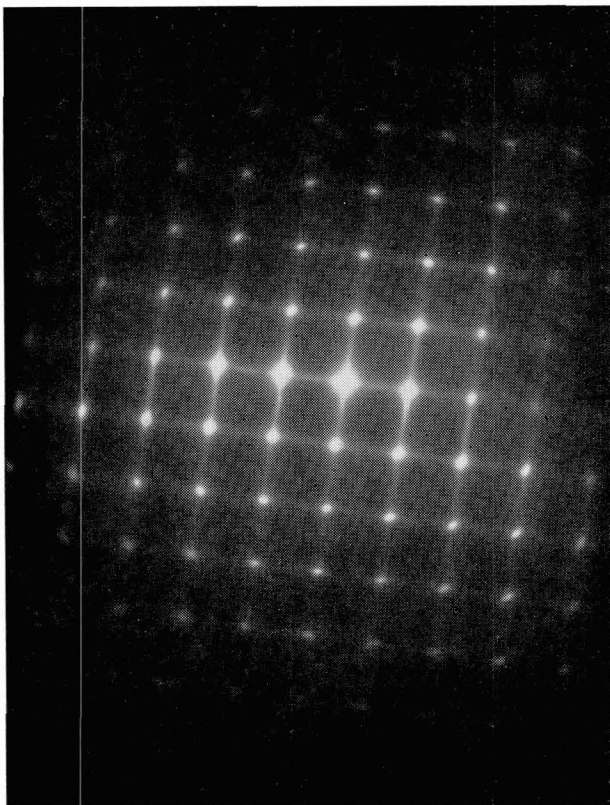


FIG. 7.

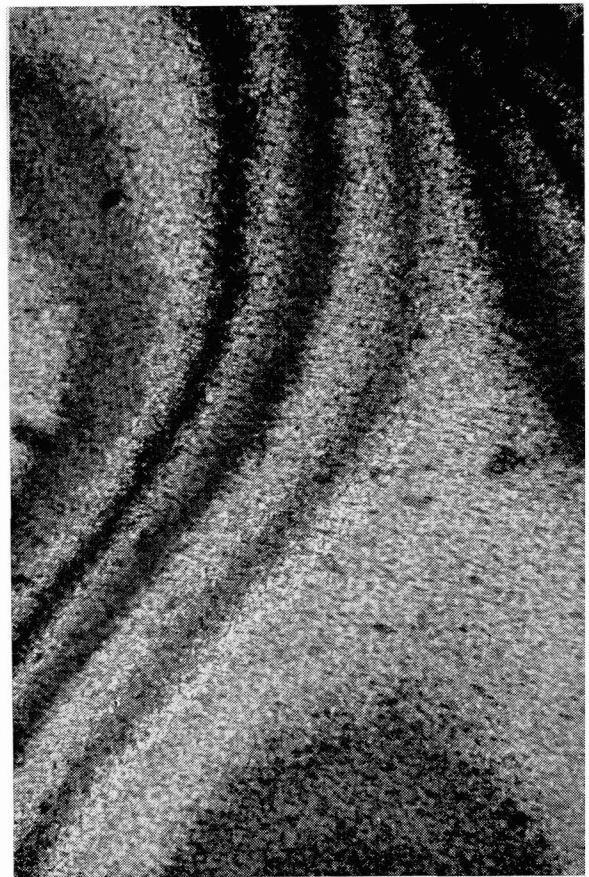


FIG. 8.



FIG. 9.

s an electron micrograph of a 5 % EuTe composition. One can see from the observable dislocation lines or loops, the high degree of perfection obtained by the coevaporation method.

**Conclusions.** — 1) Thin film co-evaporation technique is a versatile and rapid method to investigate ternary compounds.

2) PbTe-EuTe alloys form single phase solid solutions over the entire range of composition. Epitaxial films are obtained.

3) Though investigations are still under way, preliminary optical properties obtained complement structural analysis.

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