investigate the growth of nickel ferrite from a barium borate flux.

Acknowledgements

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A Method of Epitaxial Gallium Phosphide Growth

The interesting characteristics of the semiconductor gallium phosphide are now well known. It may be of practical importance for electroluminescent diodes and solar cells, but it is difficult to obtain single crystals of this compound of a useful size. Because of its high melting point ($\simeq 1450°$ C) and the high partial pressure of phosphorus over the melt (>30 atm), solution- or vapour-phase growth are the preferred techniques [1-6]. Indeed, these give good results, but they require sharply defined, experimental conditions. We describe here a technique of epitaxial growth, which is among the easiest of present methods of preparation.

Our method differs from the one described by Flicker *et al* [6] in the fact that we use, in an open tube system, pure dried hydrogen (fig. 1). The quality of purification has been tested by heating a chromium steel slab, in this hydrogen flow, at a temperature higher than 1000° C: no alteration of the polished surface appeared.

In this tube, we place two, thin wafers (each about 500 μm thick) – a polycrystalline gallium phosphide source (provided by Monsanto) and, 500 μm away, a monocrystalline gallium *arsenide* substrate. These wafers are heated by radiation above 900° C.

At this temperature, the gallium phosphide is evaporated and transported to the gallium arsenide by the gas stream. This effect is enhanced by a steep temperature gradient (40° C/cm), so that a small temperature difference of 2° C exists between the slices (source at the upper temperature). When the gallium phosphide reaches the substrate surface, it forms an epitaxial deposit at a relatively slow rate (about 7 μm/h).

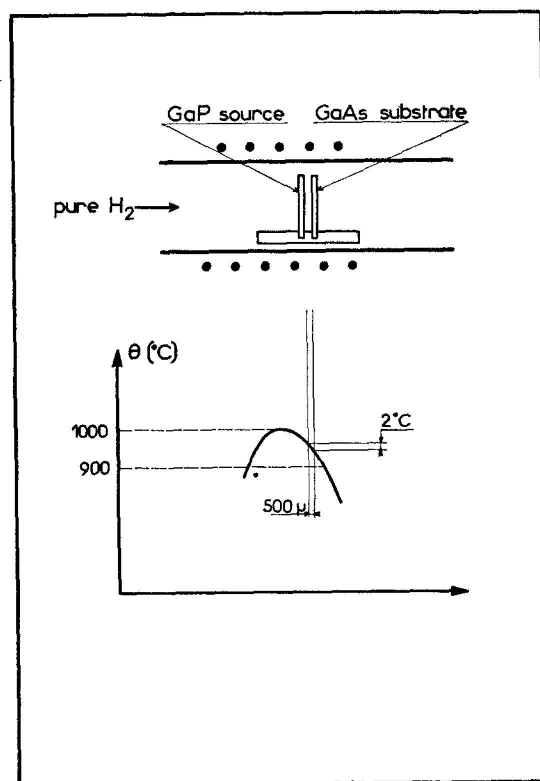

Figure 1 Apparatus used for growth of GaP.

With the conditions briefly described above, we have obtained several layers of gallium phosphide on (111) and (110) substrates. X-ray studies have demonstrated that the deposits have the same orientations as the substrates. The diffraction spots are well defined, indicating a good crystalline quality. X-ray

fluorescence has showed an arsenic content of less than 0.1%. Castaing microprobe tests have revealed that this limit is reached as close as 20 μm from the substrate/deposit interface.

A number of our deposits, separated from their substrates by abrasion or chemical etching, have been tested both optically and electrically.

From absorption measurements, the samples show a classical behaviour (fig. 2). Plotting the square root of the absorption coefficient versus photon energy, we have measured the energy gap of the material: 2.22 eV at 330° K and 2.30 eV at 80° K.

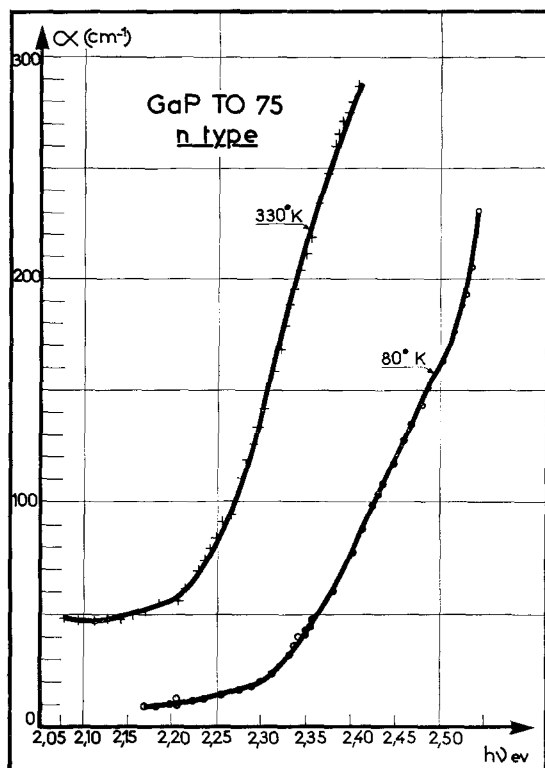

Figure 2 Typical absorption curves.

These values are in good agreement with the measurements reported by other investigators [7, 8].

We have also studied the resistivity and Hall coefficient of our samples by the Van der Pauw method [9]. When the layers are not intentionally doped, they are always of n-type (the same as the substrates). Carrier concentrations ranging from 10^{16} to $10^{17}/cm^3$, and Hall mobilities as high as 100 cm^2/V sec have been measured at room temperature (figs. 3 and 4).

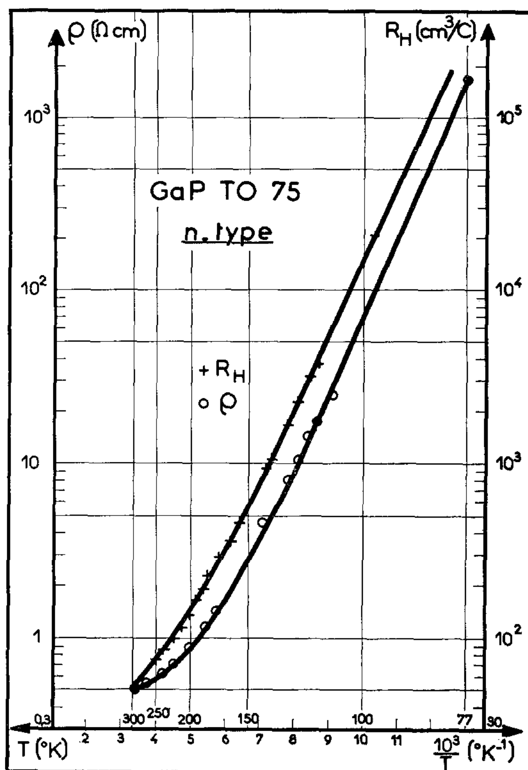

Figure 3 Typical curves of Hall coefficient and resistivity versus temperature.

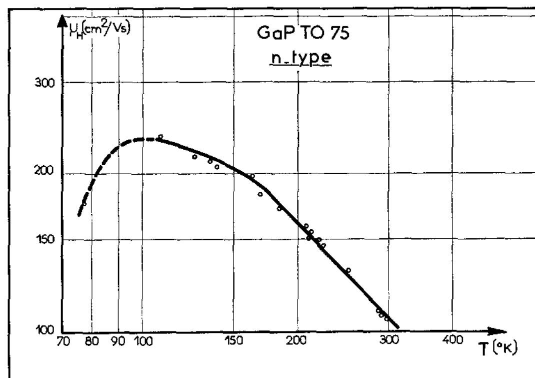

Figure 4 Typical curve of Hall mobility versus temperature.

The problem of doping can be solved by using a gallium phosphide source previously doped. By this method, we have prepared a few p-type layers (zinc-doped) using a strongly doped source, with carrier concentration of about $10^{18}/cm^3$ at room temperature, and Hall mobility higher than 60 cm^2/V sec.

These results seem to be promising and hence

will be completed by an extensive study of the growth parameters: temperature, gradient, flow rate, and, chiefly, quality of the starting materials (source and substrate).

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A New Slip System in Sapphire

During the course of high-temperature tensile tests on whiskers, the authors have obtained evidence of a slip system which has not previously been reported in sapphire. A large sapphire whisker, grown by a halide oxidation process, and having its axis along <0001>, was tensile-tested at 1200 ($\pm$ 15)° C in a modified Marsh tensile-testing machine [1]. A constant strain rate of 10^{-3} min^{-1} was used. Deformation was elastic up to a tensile stress of 93 ($\pm$ 5) kg/mm^2; at which stress, yield occurred followed by fracture. Examination of the two fracture portions revealed two sets of slip bands, the fracture having occurred at the intersection of two conjugate bands. The angle between the trace of the slip bands and the whisker axis was measured on all six {$11\bar{2}0$} faces of the whisker. The measured angles were 32 and 56°, slip steps being visible on faces where the latter was observed but not for the former. This information suggests that the slip system is {$\bar{1}011$} <$10\bar{1}2$>, for which these angles can be calculated to be 32.4 and 51.7°. Fig. 1 shows the two fracture portions orientated so that slip steps are visible on the whisker faces.

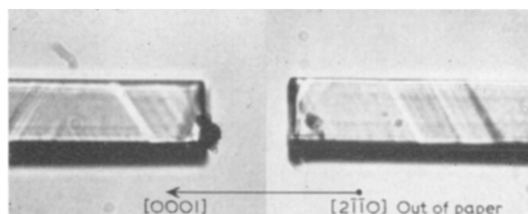

Figure 1 Optical micrograph of the two fracture portions of a sapphire whisker showing slip bands due to {$\bar{1}102$} <$10\bar{1}1$> slip. (×300)

The possible Burgers vectors for the sapphire lattice have been listed by Scheuplin and Gibbs [2], and the four smallest are shown in the table, together with information on slip planes where known.

Indices	| b | (Å)	Slip plane	Interplanar spacing (Å)	Minimum temperature of observation (°C)
$\frac{1}{3}[11\bar{2}0]$	4.75	(0001)	12.97	900
$\frac{1}{3}[10\bar{1}2]$	5.12	($\bar{1}011$)	3.48	1200
$\frac{1}{3}[20\bar{2}2]$	6.98	—	—	Not observed
$[10\bar{1}0]$	8.22	($1\bar{2}10$)	2.38	1600

The present observations of the operation of {$\bar{1}011$} <$10\bar{1}2$> at 1200° C are consistent