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ISOTHERMAL LIQUID PHASE EPITAXIAL GROWTH OF MERCURY  
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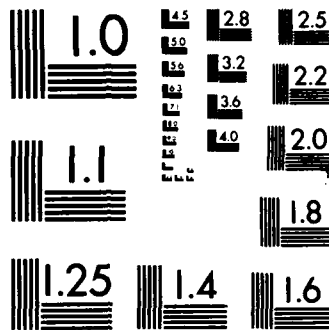
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# Isothermal Liquid Phase Epitaxial Growth of Mercury Cadmium Telluride.

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## ABSTRACT

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A method is presented for the isothermal growth of mercury cadmium telluride from a mercury or tellurium-rich melt. In accord with a proposed model, growth proceeds by HgTe deposition from the melt onto the substrate and interdiffusion between the Hg and Cd within the growing layer. Mercury-rich interdiffusion coefficients are determined from an analysis of experimental composition profiles.

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Mercury cadmium telluride consists of a continuous series of solid solutions between mercury telluride and cadmium telluride. Currently it is of great interest for use in infrared detectors in the long wavelength regime, for use in optical communications systems and in scientific spectroscopic applications. This interest is based on the continuous change of the direct bandgap as the composition varies from HgTe (-0.32 eV.) to CdTe (1.6 eV.) (1). However, there are substantial problems with growth and processing of this material, see for example Ref. (2) A large liquidus-solidus lens in the pseudobinary temperature-composition diagram makes it difficult to grow homogeneous bulk material. In addition, the material is mechanically weak, the mercury vapor pressure is high during processing and growth, and it is difficult to experimentally define the material thermodynamically since it is a ternary system. A great many growth techniques have been developed, both bulk and

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epitaxial. In this paper we present a new technique for growth from an isothermal melt and provide an analysis of the growth mechanism. In addition, mercury-rich interdiffusion coefficients are obtained from an analysis of the composition profiles.

### Experimental.

The experimental geometry for growth from a mercury-rich melt is shown in Fig.1. A CdTe {111} substrate is initially placed above a reservoir of mercury large enough to cover the substrate when the ampoule is tilted 180 degrees. Sufficient Te is added to the mercury to establish the equilibrium tellurium atomic fraction in the melt at the growth temperature for the composition of interest. We have been using a growth temperature of 500°C and tellurium fraction of 8-10%; this produces material with X values (X in  $Hg_{1-x}Cd_xTe$ ) in the range of 0.3-0.2. The ampoule is then evacuated and sealed. Growth takes place within a tipping furnace equipped with a sodium heat pipe to ensure that the system is isothermal. The ampoule is first annealed at the growth temperature to dissolve the Te into the liquid Hg. The furnace is then tipped 180 degrees, thereby immersing the substrate in the melt which then saturates by dissolving some of the substrate. Growth is allowed to proceed for 60 to 70 hours. At the end of the growth cycle, the melt is tipped off the substrate. The furnace is then turned off and allowed to cool to below 360°C before removal of the ampoule in order to avoid boiling the Hg melt which can spoil the layer surface quality. A schematic of this process is given in Fig. 2. Growth from a tellurium melt is similar except that the melt consists of the tellurium-rich

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liquid in equilibrium with the composition of interest. After growth is complete, the layers are examined optically, mounted, cross-sectioned and the composition profiles determined by electron probe microanalysis.

In our initial experiments, the melt, tellurium and substrate were all in contact as the system was heated. This produced layers with poor surface quality, probably due to Hg vapor bubble formation on the substrate as the mercury vapor pressure increased. When the melt is heated separately from the substrate, the surface quality is improved. Also, while it is possible to use the substrate to saturate the Hg-Te melt, this results in poor surface quality since a relatively large amount of CdTe must be dissolved, on the order of 80 microns for our geometry. This problem is easily avoided by adding some Cd or CdTe to the mercury melt, or by having a large area sintered "source" next to the substrate.

### **Results.**

The surfaces of the grown layers exhibit a terraced structure like that found in LPE material (3,4). Pin-holes which penetrate through a good fraction of the layer thickness were occasionally present. There is little evidence of any gross melt retention on the substrate surface.

Figure 3 shows a typical growth profile. As we will see in the next section, growth is dependent on interdiffusion so that interdiffusion coefficients can be determined from these profiles using an analytical technique developed for the isothermal vapor phase epitaxial growth method (5). The results of the interdiffusion

analysis are given in Fig. 4, along with points for mercury-rich conditions obtained by Leute and Stratmann (6). Due to the high mercury vapor pressures encountered, 8 atmospheres at 500°C (7), growth was not attempted at higher temperatures to minimize the possibility of an explosion.

### **Discussion.**

It is instructive to view this technique as a liquid phase analogue of the isothermal vapor phase epitaxial (ISOVPE) growth technique, for which we have recently proposed a mechanism (8). This vapor phase process is governed by the vapor transport of  $\text{Te}_2$  from the source to the substrate and by interdiffusion between the Hg and Cd in the growing layer. As was already mentioned, interdiffusion coefficients can be determined by an analysis of the ISOVPE growth kinetics and the experimental growth profiles. These interdiffusion coefficients are of interest both theoretically and practically because they dictate the transition region in LPE material, the stability of superlattices of HgTe and CdTe, and the rate of homogenization of material. The vapor phase growth technique is practical only in Te-rich environments since the  $\text{Te}_2$  partial pressures in Hg rich environments are extremely low. A motivation for developing the present isothermal LPE growth technique was to allow growth under Hg-rich conditions so that Hg-rich interdiffusion coefficients could be obtained.

The mechanism of growth can be seen with the aid of a schematic of the Hg-rich corner of the Hg-Cd-Te phase diagram, Fig. 5. The initial composition of the Hg-Te melt is determined by the

amount of Te added to the Hg. When the melt comes into contact with the substrate, it dissolves enough CdTe to saturate the melt, 1. This melt is now in equilibrium with solid mercury cadmium telluride of a certain composition, via tie line 2. In order to obtain the equilibrium solid composition, some HgTe deposits from the melt onto the substrate surface. This HgTe then interdiffuses with the CdTe substrate. Due to this interdiffusion, the surface of the growing layer is again no longer in equilibrium with the melt, leading to further deposition of HgTe and so the cycle continues, 3,4. Since the melt is very much larger than the amount of material deposited, the overall composition of the melt remains unchanged. However, as the layer thickens, the interdiffusion process slows so that the surface composition of the layer approaches equilibrium with the melt. Thus, fixing the Te to Hg ratio in the melt, which fixes the melt composition, allows us to control the surface composition of the layers. The Cd solubility in the melt is approximately two orders of magnitude lower than that of the Te (9) and does not play a major role in growth. In our experiments, we have used 8-10% Te in the Hg melt and have obtained layers with surface fractions of CdTe in the range of 0.3-0.2, as expected from the phase diagram work of Hering (9).

We have also observed the same growth process with layers grown on CdTe substrates from tellurium-rich melts, which is to be expected since growth is only dependent on the high interdiffusion coefficient and the thermodynamic driving force pushing the entire system, melt and substrate, towards equilibrium.

Despite the fact that the technique can only produce graded junctions, it may have some advantages as a growth technique. Mercury is the most easily purified of the three components and growth from the mercury corner should give material with fewer tellurium precipitates and mercury vacancies. Also there is the possibility for in situ mercury annealing by holding the sample at a lower temperature once growth has been completed. It has been noted in vapor grown samples that a problem exists due to impurities left on the surface of the substrate (10). This should not be a problem in the technique described here since the substrate surface can be melted back when it comes into contact with an undersaturated melt, thereby removing any surface impurities. A systematic effort is in progress to evaluate and optimize the electrical properties of the layers.

#### **Summary.**

Mercury cadmium telluride epilayers have been grown by a mercury or tellurium-rich isothermal liquid phase growth technique. Growth is the result of HgTe deposition onto the substrate. The mercury and cadmium within the layer then interdiffuse to maintain the chemical potential gradient which leads to further HgTe deposition. From an analysis of the composition profiles, interdiffusion coefficients were obtained which are in good agreement with those obtained using a conventional diffusion couple technique.

#### **Acknowledgements.**

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**Fig. 1.** The experimental geometry used in these experiments. In general, a source of Cd was added to the melt or placed next to the substrate.

**Fig. 2.** A schematic of the heating and tipping schedule used for growth.

**Fig. 3.** A plot of composition versus distance from the surface for a sample grown at 500°C for 63 hours in a melt containing 9% Te.

**Fig. 4.** A plot of mercury rich interdiffusion coefficients versus composition. Different symbols represent different growth runs, the solid triangles are the data of Leute. [6]

**Fig. 5.** A schematic of the Hg rich corner of the Hg-Cd-Te phase diagram indicating the growth mechanism. Initially, the melt is at the position denoted by the open circle on the Hg-Te binary. When the melt comes in contact with the substrate enough CdTe dissolves to saturate the melt, 1. This melt composition, denoted by the open square, is in equilibrium with solid  $\text{Hg}_{1-x}\text{Cd}_x\text{Te}$  via tie line 2. In order to approach equilibrium, some HgTe deposits from the melt onto the substrate where it interdiffuses with the CdTe, 3. This interdiffusion again forces the system out of equilibrium leading to further deposition bringing the substrate surface back towards equilibrium with the melt, 4 and so growth continues.

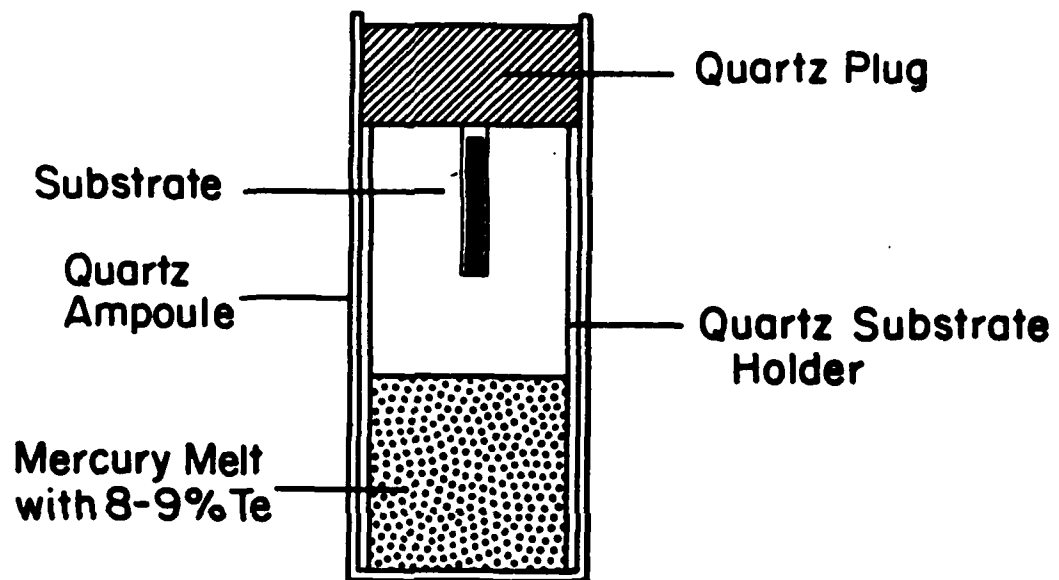


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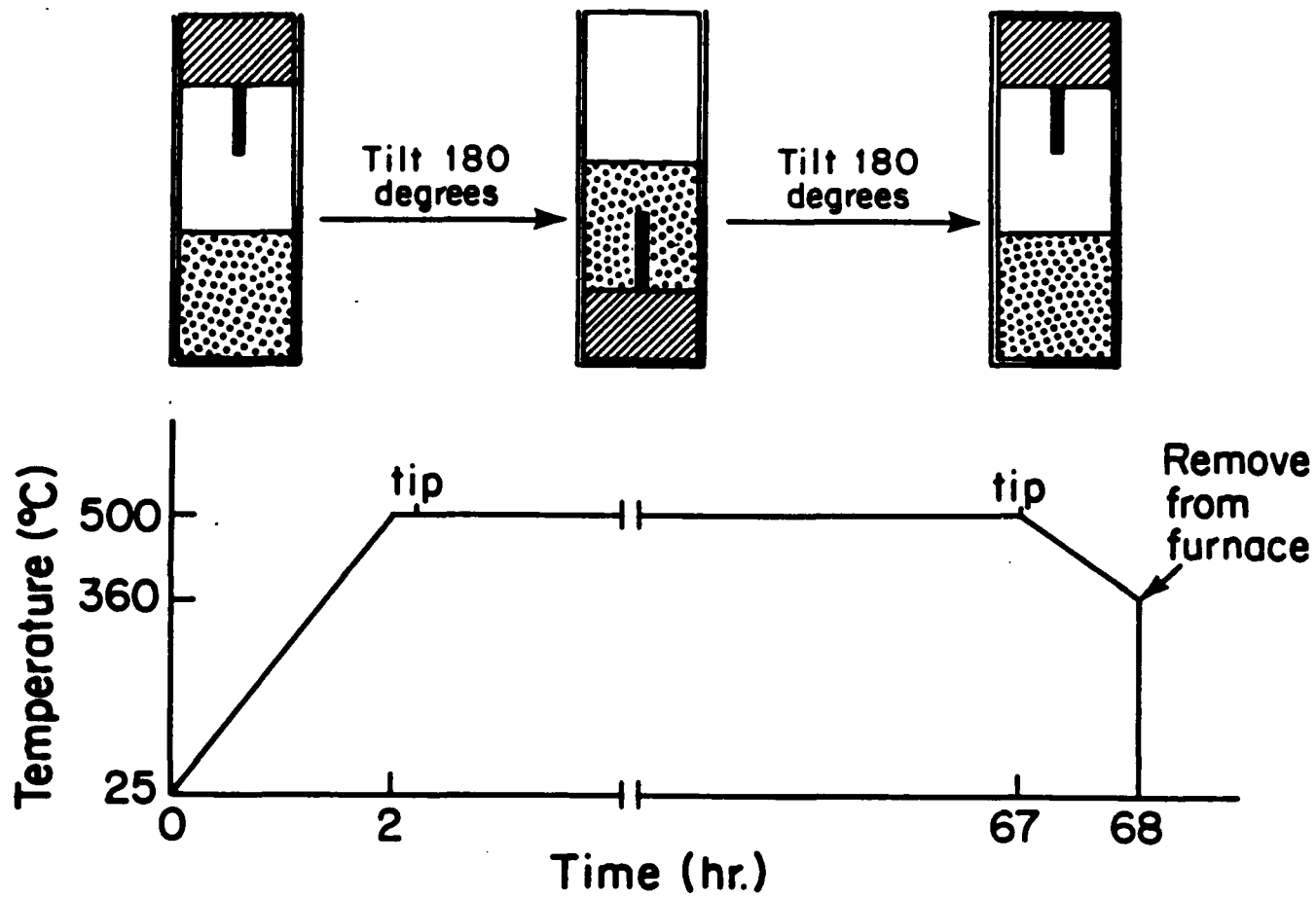


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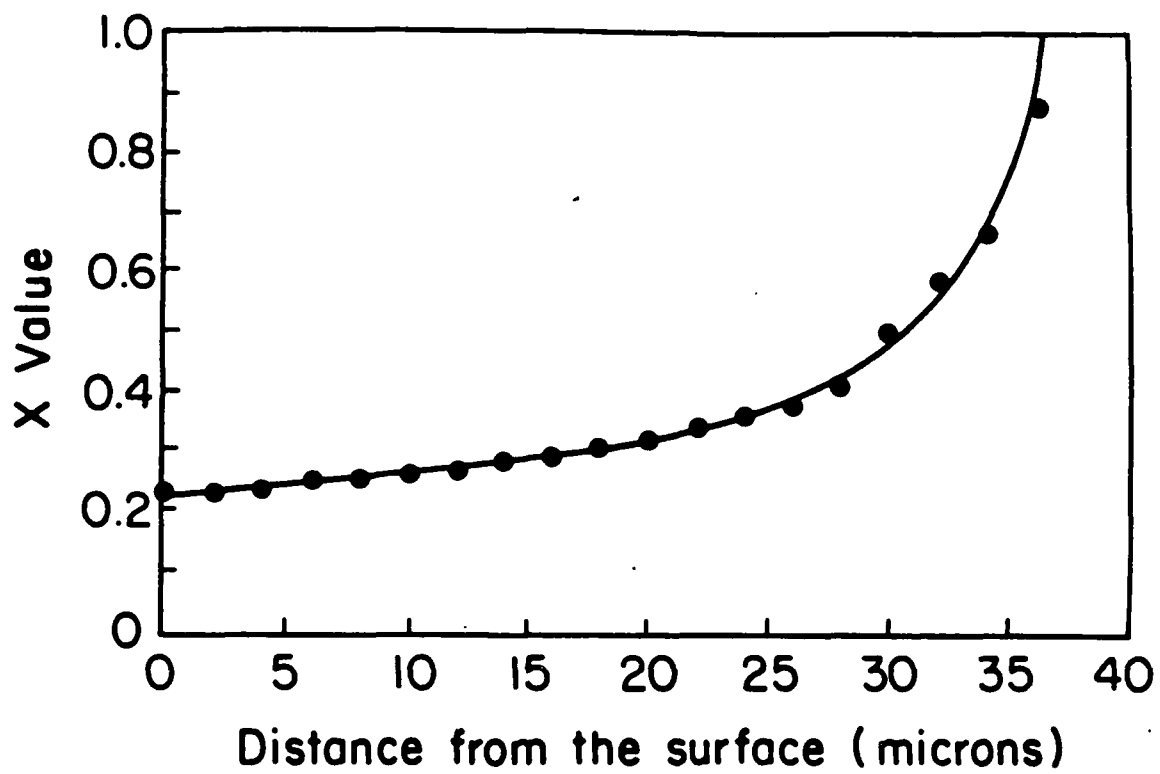


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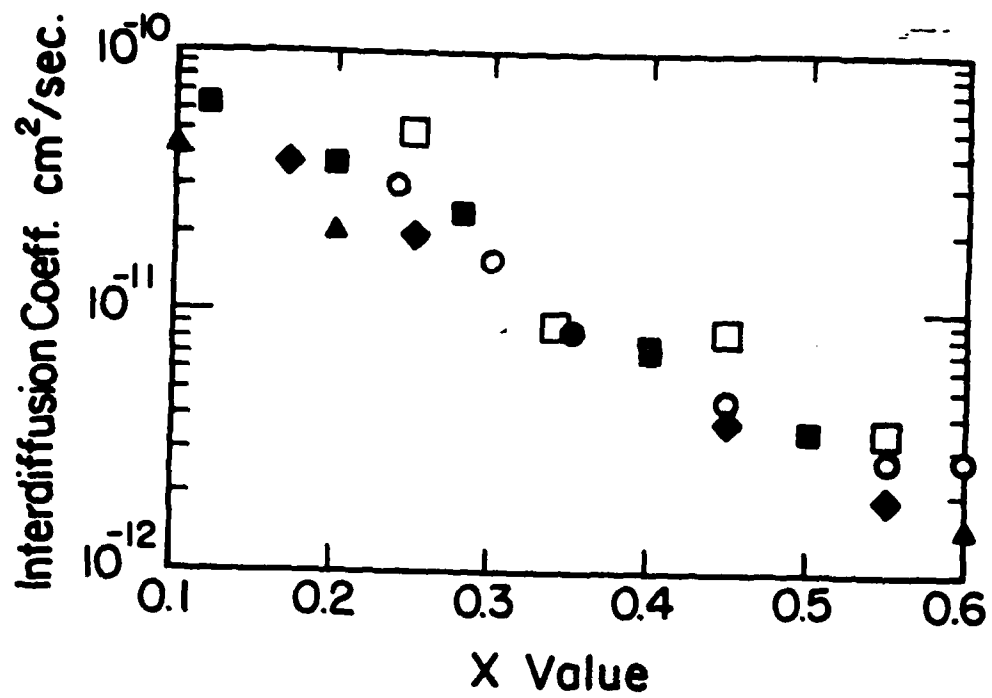


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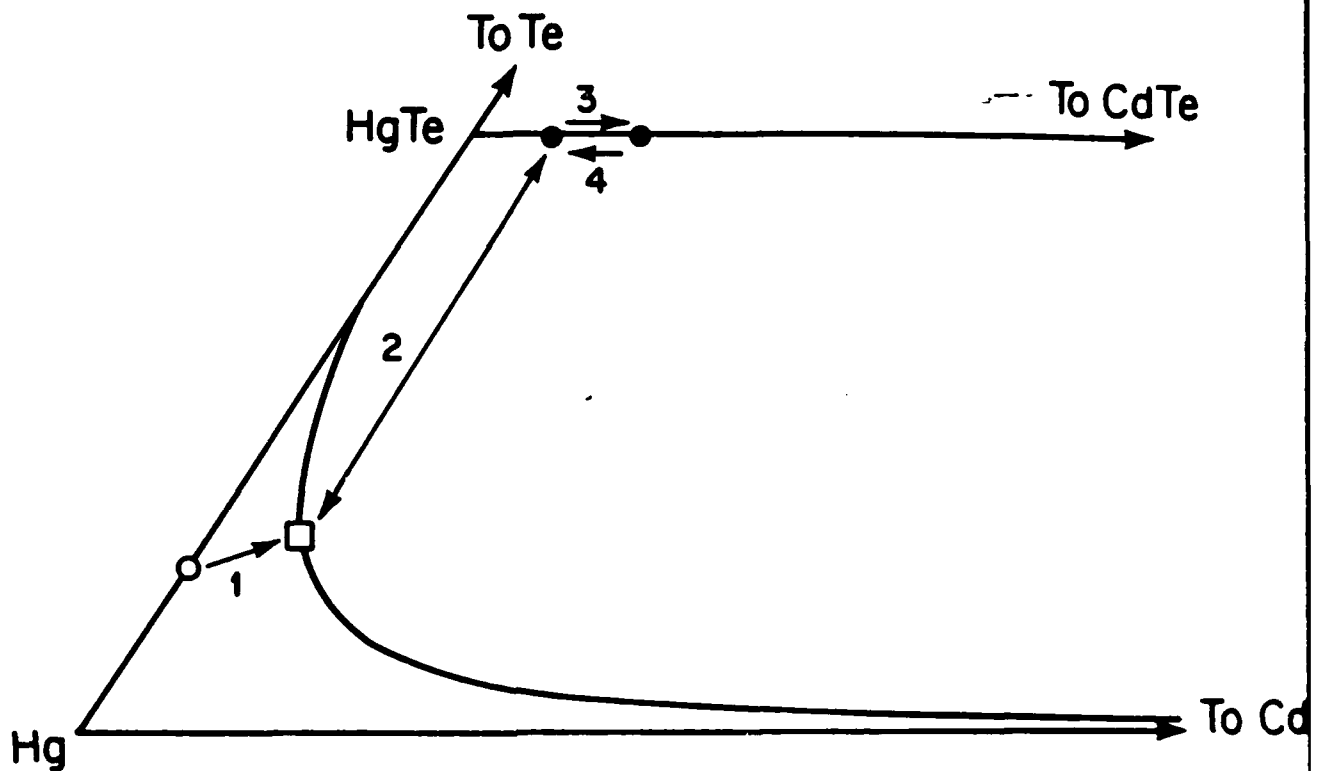


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