Preparation and Properties of Thin InSb(Te) Layers on Al$_2$O$_3$

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Abstract—Thin layers of Te-doped indium antimonide are produced on Al$_2$O$_3$ substrates by directional solidification. The effective distribution coefficient of Te is determined, and the electrical properties (resistivity, carrier mobility, and carrier concentration) of the layers are studied in the range 77–300 K. The mechanisms of carrier scattering governing the electrical properties of the layers are discussed.

INTRODUCTION

The study of thin III–V semiconductor layers is of practical interest since such layers are used in the fabrication of photosensitive multilayer systems for opto- and integrated electronics. The structural perfection and properties of such layers, especially those of doped layers, depend, however, not only on the growth conditions but also on the in-plane distribution and depth profile of the doping impurity. In the case of directionally solidified thin layers, reliable information about the effective distribution coefficients of impurities and their contribution to carrier concentration is of great importance. The associated processes in thin InSb layers have not yet been studied in sufficient detail [1–3]. The objective of this work was to grow donor-doped (Te) thin InSb layers by directional solidification, to assess the Te distribution in the grown layers, and to investigate their electrical properties.

EXPERIMENTAL AND RESULTS

Thin layers of doped InSb were produced by directional solidification. As the starting material, we used nominally undoped indium antimonide single crystals with an electron concentration of $(1–2) \times 10^{14}$ cm$^{-3}$, electrical resistivity of 0.1 $\Omega$ cm, and electron mobility of $6.2 \times 10^5$ cm$^2/(V \cdot s)$ at liquid-nitrogen temperature. Preliminary doping was performed by melting Te and InSb at 750°C over a period of 24 h in an evacuated tube. The melt was agitated by vibrating the tube. The doping level was below the solubility limit of Te $(3 \times 10^{18}$ cm$^{-3}$). The Te distribution in the resultant polycrystalline ingot was highly uniform. Doping to the desired level was performed during the growth of thin layers from molten InSb. Weighed amounts of the preliminary alloy and undoped InSb were loaded into the quartz injector of a crystallizer, which was then mounted in a resistance furnace. To obtain a uniform Te distribution in the melt, it was sufficient to hold the charge at 550°C for 1 h and the seed at a temperature 2°C below the melting point of InSb. Next, a thin layer was produced on an Al$_2$O$_3$ substrate by directional solidification in the [001] direction of the seed. The resultant layers were single-crystal, more than 20 cm$^2$ in area, and 500 µm in thickness.

Note that, during melt homogenization, impurity redistribution may occur via diffusion and convection, whereas, during layer growth in a thin (0.5 mm), broad (30 mm) gap, where no convective mixing occurs, the diffusion process is likely to dominate. One would then expect that the shape of the solidification interface will have a stronger effect on the impurity distribution in comparison with bulk crystals. The shape of the solidification interface is sensitive to the temperature distributions in the solid and liquid phases, the nature of the impurity, its distribution in the melt, and the atomic parameters of solidification kinetics.

The temperature distributions in the solid and liquid phases depend mainly on the thermophysical parameters of the substrate material and the shape of the thermal field around the growing layer. We believe that the most important factor is the lack of mixing in the thin layer since, as pointed out above, the impurity distribution ahead of the solidification interface is then governed by diffusion processes. This contributes to supersaturation upon undercooling and, in the case of a rough interface, may result in nonuniform electrical properties of the grown layer. As shown earlier [4], undercooling is possible at a doping level as low as 0.01 wt % and can be reduced by slowing down the growth rate or by creating a steeper thermal gradient at the solidification interface.
The final Te distribution in thin InSb layers can be characterized by the effective distribution coefficient \( K_{\text{eff}} \) and depends on the diffusion of background impurity atoms coming from the substrate (Al) and container material (Si, C). To evaluate \( K_{\text{eff}} \), we used the equation of directional solidification [5]

\[
(C/C_0)K_{\text{eff}} = (1 - g)K_{\text{eff}}^{-1},
\]

where \( g = 0.9 \) is the fraction of the solidified melt, \( C_0 = 4.6 \times 10^{15} \text{ cm}^{-3} \) is the initial Te concentration, and \( C = 1.6 \times 10^{16} \text{ cm}^{-3} \) is the Te concentration in the thin InSb(Te) layers.

The Te concentration in the InSb(Te) layers was determined using an EMAL-2 laser ionization mass spectrometer (sensitivity, \( 10^{-8} \text{ ppm} \)).

Substituting the above values in Eq. (1), we obtain

\[
3.47K_{\text{eff}} = 0.1\,K_{\text{eff}}^{-1}.
\]

This equation can be solved graphically, using the designations

\[
x = f(K_{\text{eff}}) = 3.47K_{\text{eff}},
\]

\[
y = \varphi(K_{\text{eff}}) = 0.1\,K_{\text{eff}}^{-1}.
\]

From the intersection of the \( x(K_{\text{eff}}) \) and \( y(K_{\text{eff}}) \) curves (Fig. 1), we find \( K_{\text{eff}} = 0.7 \).

The carrier concentration and mobility in the layers and their resistivity were determined by a dc bridge technique in a six-point configuration. The Te-doped layers, as well as undoped InSb layers, were \( n \)-type in both the intrinsic and impurity regions. The table compares the electrical properties of the InSb and InSb(Te) layers at 77 and 300 K. The electron mobility in the thin layers is lower than that in bulk crystals (\( \mu_{77} = 6.2 \times 10^5 \text{ cm}^2/(\text{V s}) \)). At the same time, the electrical properties of our layers are superior to those reported earlier for InSb thin layers and films [6–9].

To elucidate the main mechanisms of carrier scattering, we analyzed Hall mobility versus temperature data (Fig. 2). It follows from our results that, above 200 K,