

Reprinted from THE PHYSICAL REVIEW, Vol. 135, No. 5A, A1453-A1459, 31 August, 1964  
Printed in U. S. A.

## Artificial Metals: InSb, the Sn Alloys with InSb, and Metallic InTe†

A. J. DARNELL AND W. F. LIBBY

Department of Chemistry and Institute of Geophysics, University of California, Los Angeles, California

(Received 9 April 1964)

The metallic forms of indium antimonide, indium telluride, and the metallic alloys InSbSn, InSbSn<sub>2</sub>, and InSbSn<sub>4</sub>, were prepared at high temperature and high pressure, cooled, and subsequently quenched to -197°C before release of the pressure to one atmosphere. The metastable metallic forms can be retained at one atmosphere pressure at low temperatures indefinitely and studied conveniently. InSb(II) and its metastable alloys with tin have lattice parameters essentially identical with those of metallic tin. The lattice parameter of the cubic form of indium telluride is  $6.177 \pm 0.002 \text{ \AA}$  at 25°C. The compressibilities of InSb(II), InSb(I) and of Sn( $\beta$ ) at -197°C are 0.9, 3.6, and  $3.1 \times 10^{-6} \text{ bar}^{-1}$ , respectively. The compressibilities of InTe(I) and InTe(II) at 25°C are 6.3 and  $3.8 \times 10^{-6} \text{ bar}^{-1}$ , respectively. The heat of transformation  $\Delta H_{210}^{\circ}$  (1 atm) InSb(II)  $\rightarrow$  InSb(I) is  $-4.77 \pm 0.04 \text{ kcal per mole}$ . The resistivity of InSb(II) at 77°K is  $77 \times 10^{-6} \Omega\text{-cm}$ . The velocity of sound in polycrystalline InSb(II) is approximately 3900 m/sec. The Brinell hardness numbers of InSb(II) and Sn( $\beta$ ) at 77°K are 230 and 46 kg mm<sup>-1</sup>. InTe(II) is diamagnetic, its susceptibility is  $-0.14 \text{ emu g}^{-1}$ .

### I. INTRODUCTION

IT has been demonstrated experimentally<sup>1-7</sup> by Kennedy and his co-workers, by Drickamer and his co-workers, and by others that diamond-type lattices, when subjected to pressure, suffer a transformation into a denser, more highly coordinated state, which is metallic. The general nature of the phase diagram is that the melting point of the nonmetallic state falls as the pressure is increased until a triple point is reached and the solid-solid transition corresponding to a change from a nonmetallic to a metallic state occurs

after which the melting point rises again with an increase in pressure. It is thought that this general phase diagram applies for all the members of group IV; carbon, silicon, germanium, etc., and to the binary compounds one column removed from group IV in the periodic table such as boron nitride, aluminum phosphide, gallium arsenide, indium antimonide, etc., and even those two removed from group IV (though less work has been done on them) such as zinc selenide, which averages four valence electrons per atom.

It is our purpose here to describe a technique of removing these new materials from the high-pressure apparatus in which they were produced in order that their properties can be studied more completely. The difficulties and limitations of having to work within a high pressure chamber are very great.

### II. THE TECHNIQUE

It is very well known in chemistry that a transition from one solid phase to another or from a liquid to a solid or, in some instances, in the opposite direction can be slow and dependent upon nuclei. The transformation of metallic tin to the semiconducting, diamond-type structure at low temperatures well illustrates this.

† This research was supported by the Directorate of Chemical Sciences, United States Air Force Office of Scientific Research, Grant No. AF-AFOSR-245-64.

<sup>1</sup> A. Jayaraman, R. C. Newton, and G. C. Kennedy, *Nature* **191**, 1288 (1961).

<sup>2</sup> A. Jayaraman, W. Klement, Jr., and G. C. Kennedy, *Phys. Rev.* **130**, 540 (1963).

<sup>3</sup> B. J. Alder and R. H. Christian, *Phys. Rev. Letters* **8**, 367 (1961).

<sup>4</sup> H. L. Suchan and H. G. Drickamer, *J. Chem. Phys.* **31**, 355 (1959).

<sup>5</sup> S. Minomura and H. G. Drickamer, *Phys. Chem. Solids* **23**, 451 (1962).

<sup>6</sup> G. A. Samara and H. G. Drickamer, *Phys. Chem. Solids* **23**, 457 (1962).

<sup>7</sup> G. A. Samara and H. G. Drickamer, *J. Chem. Phys.* **37**, 408 (1962).