such powder, massive white tin was transformed to the grey allotrope at −40° C. in an evacuated and 'gettered' glass tube. Considerable volume changes occur during transformation, and the grey tin formed as a more or less granular powder. This loose powder was re-transformed to white tin at room temperature and shaken to one end of the tube. It was then heated at 220° C., for 48 hr.

The powder had formed a coherent, but friable, mass, which was removed from the tube in one piece. Specimens from this were prepared for micro-examination, which showed much evidence of growth across particle boundaries, indicating that sintering had taken place. It is, of course, to be expected that sintering would take place much more rapidly and completely if the powder were first compacted, but it may be concluded that, in the absence of oxide films, tin powder will sinter when heated.

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Thermoelectric Properties of Bismuth Telluride and its Alloys

PREVIOUS publications from this Laboratory have described the progress made with bismuth telluride in connexion with thermoelectric refrigeration or generation. With a thermo-junction between p-type bismuth telluride and bismuth the maximum temperature difference obtained[1] was 26° C., and between p- and n-type bismuth telluride[2] 40° C. This corresponded with a figure of merit $\eta\sqrt{\sigma/K}$ of 0·0335 degree$^{-1/2}$. Here η is the thermoelectric power, σ the electrical conductivity, and K the thermal conductivity.

In our work on this compound in 1956 we were able to make p- and n-type bismuth telluride with greater uniformity and to realize more exactly the optimum thermoelectric power, which is near 200 μV./deg. C. The outcome of this was a maximum temperature difference of 65 deg. C. at a mean temperature of 17° C. The physical properties of the material are consistent with those reported by me at the Garmisch conference in September 1956 [3], except that Hall electron mobilities as high as 300 cm.^{2} volt^{-1} sec.$^{-1}$ have been obtained in more recent material.

A temperature difference of 65 deg. C. has been quoted recently by Shilliday[4], of the Battelle Laboratories. In Russian work, Sinani and Gordyakova[5] have quoted a figure of merit of 0·049 for one component of a junction. This was n-type, and consisted of an alloy of 80 per cent bismuth telluride and 20 per cent bismuth selenide. The highest temperature difference quoted in Russian work[6] appears to be 70 deg. C., indicating that their p-type material is inferior to the n-type quoted, since if both components of a junction have a figure of merit of 0·049, the maximum temperature difference is larger than 70 deg. C., as indicated later.

It is to be expected, as discussed by Joffe[7], that in alloys the thermal conductivity will be less than that of either single component, because the substituted atom causes phonon scattering. In favourable circumstances this can be achieved without appreciably increasing the electron scattering. In accordance with this, we have recently studied alloys of bismuth telluride – bismuth selenide, bismuth telluride – antimony telluride, bismuth telluride – bismuth sulphide and also alloys of bismuth telluride – antimony telluride containing either selenium or sulphur. With some compositions both p- and n-type material with the optimum thermoelectric power has not yet been obtained, and in fact this is the case with alloys giving the lowest thermal conductivity. Taking the most favourable n- and p-type alloys so far prepared, we have been able to obtain a mean figure of merit of 0·049 for the junction, corresponding with a maximum temperature difference of 80 deg. C. for a mean temperature of 17° C. This results primarily from the fact that substitution of antimony for bismuth lowers the lattice component of the thermal conductivity, K_0, from 0·0157 for bismuth telluride to a minimum of 0·010 ohm. cm.$^{-1}$ deg. C.$^{-1}$ at about 50 atomic per cent of antimony, while the electron mobility is not reduced. Substitution of sulphur or selenium for tellurium in any $(Sb–Bi)_2–Te_3$ alloy causes a further small reduction in K_0, but the amount which can usefully be substituted is restricted because of electron scattering.

Our work on the optical properties[8] indicates that on substituting selenium for tellurium in bismuth telluride, there is a change in band structure near the composition Bi_2Te_2Se, which may be associated with the decrease in mobility on adding selenium because of an increase in inter-valley scattering. We have not so far been able to obtain infra-red transmission through $(Bi–Sb)_2–Te_3$.

I would like to acknowledge the collaboration of several scientists working as a team on this subject. A. R. Sheard is responsible for preparing the material, H. J. Goldsmid for studying thermal conductivity and thermoelectric power, J. R. Drabble for investigating the galvanomagnetic effects, and I. G. Austin for examining the optical properties. P. A. Walker and B. Yates are extending the measurements down to liquid-helium temperatures. In addition to the papers referred to above, some of the more recent work has been published[9], and other papers are in preparation[10].

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