J. J., ZEIGER H. J. and
v. Lett. 4, 64 (1960).
J., *Philips Res. Rep.* 18,
s in Electronics and Tele-
part I, p. 475. Academic
em. Solids 8, 227 (1959).
K. K. and SHILALNIKAS
ternational Conference on
ors, p. 149. The Institute
Society, London (1962).
5, 618 (1964).
ER J., *J. Appl. Phys.* 36,
N. I. and SCHMIDT-
-State Commun. 1, 226
N. I. and SCHMIDT-
dings of the 7th Inter-
7. Paris (1964).
024 (1960).
Y., *J. Phys. Soc. Japan*
ntrol 5, 157 (1958).
mmunication).
Phys. Rev. 136, A1449

J. Phys. Chem. Solids. Pergamon Press 1966. Vol. 27, pp. 1519–1529. Printed in Great Britain.

PHYSICAL BEHAVIOR OF GERMANIUM UNDER SHOCK WAVE COMPRESSION*

R. A. GRAHAM, O. E. JONES and J. R. HOLLAND

Sandia Laboratory, Albuquerque 87115, New Mexico

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Abstract—Shock wave compression measurements from 20 to 140 kb and resistivity measurements under shock wave compression to 40 kb are reported for Ge in the [111] orientation. The Hugoniot elastic limit is found to be 44 ± 4 kb and a phase transition in the pressure range from 114 to 122 kb at about 160°C is identified. The transition occurs at a volume between $0{\cdot}870\ V_0$ and $0{\cdot}880\ V_0$. A shock wave velocity measurement in the mixed phase region allows the slope of the phase diagram to be determined as $-3{\cdot}1 \times 10^{-2}$ kb °C^{-1}. The pressure and volume data are in good agreement with the static work; these data, when combined with the slope of the phase diagram, clearly identify the transition as the solid–solid transition to the white tin structure. The observed exponential decrease of resistivity with elastic strain allows an energy gap change computation which agrees with theoretical calculations for silicon to 60%. Unusual features of the band structure of one-dimensionally strained [111] Ge are discussed. The new technique developed is generally applicable for shock compression and resistivity measurements on semiconductors.

INTRODUCTION

PREVIOUS shock wave compression experiments[1] on single crystal germanium have revealed a complex wave structure resulting from a high Hugoniot elastic limit of about 40 kb and a suspected phase transition at about 130 kb. Because of the high elastic limit, large, elastic one-dimensional compressions are uniquely achieved in shock wave experiments below the Hugoniot elastic limit. Since large elastic compressions can be achieved, measurements of the resistivity of germanium under shock loading conditions in the elastic range may provide a measure of the energy gap change induced by one-dimensional strain and a verification of theoretical calculations[2,3] if the germanium samples behave intrinsically. In addition, resistance-time measurements of shock waves produced by symmetrical projectile impacts provide the basis for a method to determine the stress–volume relation for semiconductors. New techniques are required for these measurements because of the complex wave structure of germanium and the necessity of a close coupling between measurements of the stress and electronic properties.

The purpose of this paper is twofold. Both shock wave compression results and measurements of the resistivity of germanium in one-dimensional strain will be presented. The shock compression results give a measure of the Hugoniot elastic limit and give thermodynamic data which permit the transition to be identified as polymorphic. The resistivity measurements are found to provide an approximate verification of the theoretical predictions. A new experimental technique is described which permits a measurement of both shock compression and resistivity from a common experimental record and avoids the wave interaction problem inherent in free-surface velocity measurements. Section 1 includes a description of the experimental arrangement and an analysis of the form of the predicted resistance-time behavior. The results and a discussion of the stress–volume measurements are presented in Section 2. Finally, Section 3 shows the results of and a discussion of the resistivity measurements. The authors are aware that the manuscript contains results which are normally of interest to readers in different

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