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Research paper

Effect of pressure and electrical resistivity on ultrasonic properties of MgB_2 single crystal at low temperatures

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ABSTRACT

Higher order elastic constants have been calculated in semi-metallic superconducting single crystal magnesium diboride (MgB_2) at low temperatures following the interaction potential model. Second order elastic constants are used for the determination of other ultrasonic parameters. The pressure variation of the ultrasonic velocities is evaluated using the second order elastic constants. The ultrasonic attenuation due to electron-phonon interaction has been computed at different pressures and in low temperatures range 40–90 K. We have also calculated the electron-viscosity at different low temperature, needed for the calculation of ultrasonic attenuation. The behaviour of ultrasonic attenuation is almost similar to its inverse electrical resistivity. The electron–phonon interaction, which is the dominating cause of ultrasonic attenuation, occurs at lower temperatures in MgB_2 single crystal. It has been found that the electrical resistivity is the main contributor to the behaviour of ultrasonic attenuation as a function of temperature and the responsible cause of attenuation is phonon-phonon interaction.

1. Introduction

Ultrasonic offer the possibility to detect and characterize microstructural properties as well as flaws in materials, controlling materials behaviour based on physical mechanism to predict future performance of the materials. In the field of nondestructive characterization of materials, the use of ultrasonic method is very constructive to extract the different properties of different materials. This is also a helpful technique in many other imperative research areas which include the detection of poor cohesion and adhesion in adhesive joints, characterization of microstructures, appraisal of defects, thickness of sheet materials, detection of damage in composites, the inspection of surface, and measurement of the elastic properties of the materials. The study of the interaction of sound with materials is a versatile tools for determination of the elastic constants. The elastic constants of material are associated with the thermophysical properties of the materials such as specific heat, Debye temperature, and Grüneisen parameters, which provides better understanding of the solid state behaviour of the materials. With the help of these elastic constants, one can easily measure the velocity of longitudinal and shear waves. The relation between elastic constants and velocity is given by formula, $V = \sqrt{\frac{C}{\rho}}$ where 'C' is elastic constant and 'ρ' is the density of that particular material. The velocity of longitudinal and shear waves is directly related to ultrasonic attenuation at low temperature. Also the elastic constants provide the useful information about the Debye temperature and Debye average velocity at different temperatures [1–4].

The phenomenon superconductivity was discovered over a century ago by Kamerlingh Onnes in metallic mercury below 4 K. After several years many other types of superconductors were discovered with critical temperature below 20 K [5]. Magnesium diboride was discovered in early 1950′s but the superconducting behaviour was defined in 2001 with critical temperature 38–40 K [6–11]. The superconductivity behavior of MgB_2 received extensive scientific interest by the researcher and scientist in recent years because of their simple hexagonal crystal structure. In MgB_2 the boron atoms form graphite like sheet separated by hexagonal layer of magnesium atoms. At equilibrium condition it has AlB_2 type structure with lattice parameters 'a' and 'c' about 3.076 Å and 3.525 Å respectively at zero pressure. The great theoretical as well as experimental progress has been made in last several years [13–15].

In former times the second order elastic constants (SOECs) was calculated by Zong et al. and also the second as well as third order elastic constants (TOECs) were calculated by Wang et al. using the first principle method in superconducting MgB_2 single crystal [5]. The low temperature resistivity has been reported by Schneider et al. [16], Sologubenko et al. [6], Tajima et al. [13] and many others. The value of temperature dependent electrical resistivity is taken from literature [16].

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