TEMPERATURE AND PRESSURE EFFECTS ON THE ELASTIC MODULI OF GADOLINIUM SINGLE CRYSTALS

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ABSTRACT

The effects of hydrostatic pressures up to 3 kbar on the single crystal elastic moduli of Gd metal have been measured at 298 K and 273 K. In addition, the effect of pressure on the temperature dependence of c_{33} between 298 and 273 K has been observed. With exception for the c_{44} shear mode the pressure coefficients of the stiffness moduli and the Gruneisen mode gammas are significantly decreased by ferromagnetic ordering. The isothermal pressure derivative of the bulk modulus is 1.68 at 273 K in contrast to 3.11 at 298 K.

The effects of ferromagnetic ordering observed in the temperature dependence of the elastic moduli are mostly intrinsic effects not caused by the volume magnetostriction. The pressure dependence of T_c as indicated by the c_{33} modulus is — 1.60 K/kbar.

RÉSUMÉ

Les effets de la pression hydrostatique jusqu'à 3 kbar sur les modules élastiques d'un monocristal de Gd ont été mesurés à 298 K et 273 K. De plus, on a observé l'effet de la pression sur la variation thermique de c_{33} entre 298 K et 273 K. L'ordre ferromagnétique réduit sensiblement les coefficients de pression des modules d'élasticité, à l'exception de c_{44}, et les gammas de Grüneisen. La dérivée isotherme, par rapport à la pression, du coefficient en volume est 1,68 à 273 K au lieu de 3,11 à 298 K.

Les effets de l'ordre ferromagnétique que l'on constate dans la variation thermique du module élastique sont dus essentiellement à des effets intrinsèques qui ne résultent pas de la magnétostriction en volume. La variation de T_c avec la pression indiquée par le module c_{33} est de — 1,60 K/kbar.

Introduction

Several papers have recently appeared which pertain to certain aspects of ultrasonic wave propagation in ferromagnetic Gd metal. Luthi et al. have shown a pronounced peak in ultrasonic attenuation for the c_{33} longitudinal mode near T_c ($\sim$ 290 K) which arises from the volume magnetostriction coupling mechanism [1]. Long, et al. have published some data regarding the effects of changes in magnetic anisotropy constants on c_{33} at 236 K, which indicate a type of ΔE effect [2]. Brooks et al. have calculated the effect of magnetoelastic coupling on the temperature dependence of the magnetic anisotropy constants [3]. Rosen has measured the changes in polycrystalline elastic parameters with temperature [4]. The present

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work presents the effects of temperature and high pressure on all of the single crystal elastic stiffness moduli of Gd.

The purpose of the work it twofold : (1) to determine whether the indirect exchange interaction between the *f* electrons and the conduction band, which leads to the observed magnetic structures in rare earth metals, produces significant intrinsic changes in the elastic moduli, (2) to obtain some basic information about the Grüneisen constants for the lattice vibrational modes in the paramagnetic and ferromagnetic phases. The measurements of the temperature dependence of the elastic moduli at atmospheric pressure are included in the Proceedings of the 6th Rare Earth Conference [5] ; in this paper we will only briefly review this part of the work and concentrate on the derivation and use of the high pressure measurements carried out at the University of Hawaii.

Experimental procedure

The five independent elastic stiffness moduli for h.c.p. crystals are determined by measuring the velocities of pulsed ultrasonic waves propagated parallel, perpendicular, and 45° to the " c " axis. The relationship of the moduli to the wave modes are given in Table I. The diagonal moduli c_{ij} $(i = j)$ are determined directly from ρv^2, where ρ is the mass density and v is the particular wave velocity. The calculation of c_{13} involves the quasicompressional wave velocity, as well as c_{11}, c_{33} and c_{44} [6].

The purity of our Gd crystals has not been chemically evaluated. On the basis of the magnetic Curie temperature ($T_c = 289.5$ K) that was carefully measured for this material, we estimate from the relation of Cadieu and Douglas [7] that the resistivity ratio $R_{273\,K}/R_{4\,K}$ was approximately 25.

TABLE I

Relation of elastic moduli to acoustic wave modes propagated in Gd crystals

Modulus	Wave propagation direction	Type mode
c_{11}	90° to "c"	compressional
c_{33}	parallel to "c"	compressional
c_{44}	parallel to "c"	shear 90° to "c"
c_{44}	90° to "c"	shear parallel to "c"
$c_{66} = \frac{1}{2}(c_{11} - c_{12})$	90° to "c"	shear 90° to "c"
c_{13}	45° to "c"	quasi-compressional (Q.L.)

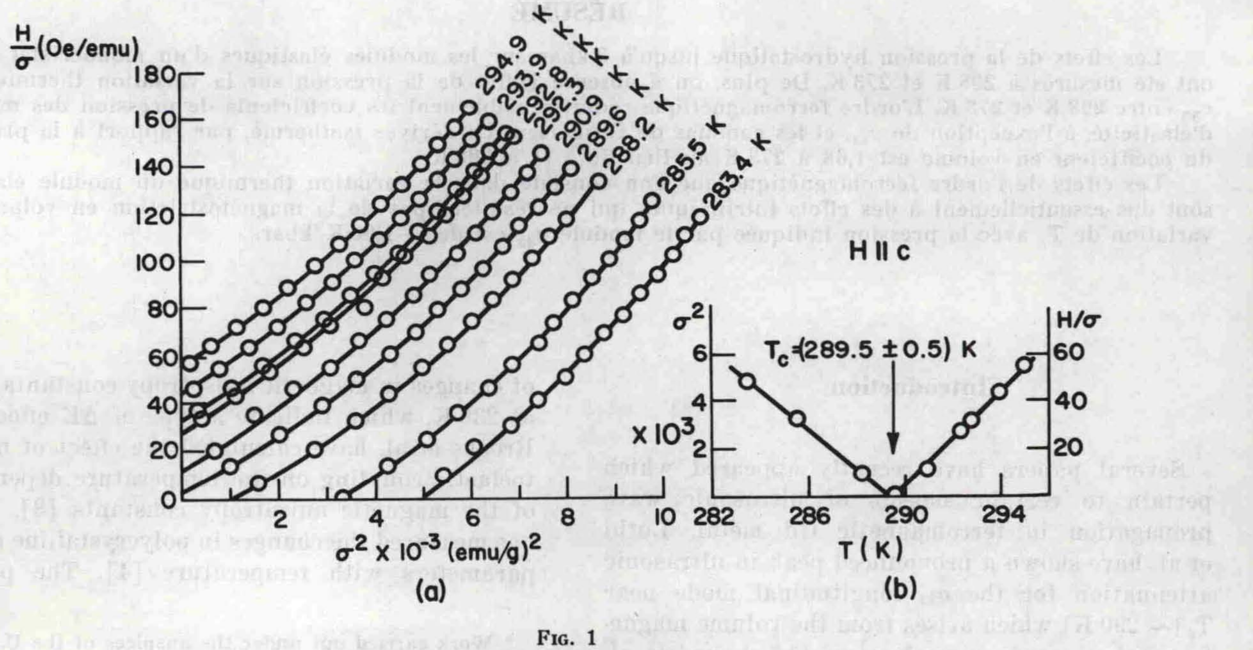

FIG. 1

Determination of the magnetic Curie temperature T_c, from magnetization (σ) vs. field (H) data for $H_{\parallel}$ "c".