EFFECT OF $\alpha$-RECOIL DAMAGE ON THE ELASTIC MODULI OF ZIRCON AND TOURMALINE

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ABSTRACT

The elastic moduli of natural radiation-damaged zircons and thermal neutron irradiated tourmalines have been studied. A systematic and very marked decrease of the elastic moduli with radiation damage has been observed. The bulk moduli obtained for the damaged zircons and tourmalines were compared with the theoretical estimates of bulk moduli for irradiated materials containing spherical and nonspherical distributions of defects, displacement cascades, voids and cracks.

1. INTRODUCTION

In an earlier paper we have reported that the elastic constants and the lattice parameters of several natural zircon crystals have systematical and very marked differences due to the transformation of zircon to the amorphous (metamict) phase caused by the radioactive uranium and thorium impurities. The energetic $\alpha$-particles and recoil atoms, released by the disintegration of the radioactive impurities, cause radiation damage and transform zircon into a low-density amorphous form.

Similar $\alpha$-recoil damage may be induced in boron-containing crystals by thermal neutron irradiation due to $^{10}\text{B}(n,\alpha)\text{Li}$ nuclear reaction. The two energetic fragments released by this reaction also produce lattice defects and may transform the boron compounds into low-density amorphous form. In a recent publication we have also reported the effect of thermal neutron irradiation on the structure and elastic moduli of boron-containing tourmaline crystals. A brief summary of the two previous reports about the effect of $\alpha$-recoil damage on the elastic moduli of zircon and tourmaline is presented here.

2. ELASTIC DATA OF THE DAMAGED ZIRCONS

Elastic wave velocities of seven different zircon samples of densities from 4.70 to 3.90 g/cm$^3$, covering the whole density spectrum for the transformation of zircons into amorphous form, have been measured by the ultrasonic pulse-echo method. The details of sample preparation and the experimental techniques are described in reference 1.

The measured elastic wave velocities and the calculated elastic moduli are plotted versus density of the samples in Fig.1 and 2. A glance at Fig.1 and 2 reveals a number of interesting features in the behaviour of the elastic moduli of the zircon samples. All the longitudinal and shear moduli, with the exception of $C_{66}$, decrease systematically and markedly with the radiation damage and approach the saturation values of 154 GPA and 49 GPA, respectively.

* GPA is gigapascal.
The largest decrease occurs in $C_{33}$ (69%), which is the largest modulus for undamaged zircons\(^5\). The smallest shear modulus $C_{66}$, which also has anomalous pressure derivatives\(^6\), does not decrease with decrease of density but remains essentially constant approaching the same saturation value for the shear moduli. The systematic decrease in the elastic moduli as well as in the elastic anisotropy indicate that as the radiation damage increases zircon crystals gradually become isotropic.

As seen in Fig.2, the curves for the longitudinal and shear moduli versus density of zircon show a sigmoid pattern: the rates of decrease of the elastic moduli are initially less rapid, then decrease more rapidly from densities 4.60 to about 4.50 g/cm\(^3\). After densities of 4.50 g/cm\(^3\) the rates of decrease again reduce gradually. A similar behaviour was also observed in the x-ray diffraction patterns of the zircon samples\(^1\). The peak positions (28 values) decrease relatively slowly at first, then decrease more rapidly for densities of 4.60-4.50 g/cm\(^3\). After densities of 4.50 g/cm\(^3\) the

Fig.1. Elastic wave velocities versus density of zircon samples. The solid bars indicate points obtained from several different directions of the unoriented zircon samples 4-7.

Fig.2. Elastic moduli versus density for zircon samples. $C_L$ and $C_S$ denote $[110]$ and $[011]$ longitudinal moduli, $C_P$ and $C_{QS}$ denote $[011]$ shear moduli polarized along $[100]$ and $[011]$, respectively.