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Modifications in the mechanical characteristics of $YFeO_3$ crystals on irradiation

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Abstract

Results of 50 MeV Li^{3+} ion irradiation on the mechanical behaviour of flux-grown $YFeO_3$ crystals are reported. Vicker's microhardness, fracture toughness, brittleness index of the (1 1 0) face of irradiated $YFeO_3$ crystals, in the load range 0.098–0.98 N, are calculated and compared with the values of unirradiated crystals. Applying the concept of Hays and Kendall, the load-independent values are estimated for the irradiated and unirradiated crystals. The decrease in the value of microhardness on irradiation is explained to be as a result of amorphization in the material. Classification of cracks is dealt with and it is reported that the transition from Palmqvist to median type of cracks occurs at higher loads. The average values of fracture toughness, brittleness index and yield strength are also determined for the irradiated crystals.

Keywords: Irradiation; Microhardness; Fracture toughness; Brittleness index; $YFeO_3$

1. Introduction

Mechanical characteristics of many flux-grown single crystals have been studied. The microhardness values of $RAlO_3$ (where R = Eu, Gd, Dy, Er, La, Sm and Ho), $RCrO_3$ (where R = Y, Gd, Yb, La, Eu and Dy) and $RFeO_3$ (where R = Gd, Tb, Dy, Ho, Er and Yb) crystals have been reported [1,2]. The study was aimed at the verification of the general applicability of Hays and Kendall's law [3] by taking microhardness values on a large number of the samples of rare-earth perovskites without giving reference to any specific plane. A detailed study of the microhardness on different crystallographic planes, including time dependence of hardness, indentation-induced crack propagation, fracture toughness, brittleness index and yield strength of $RFeO_3$ (R = Y, Er, Ho and Gd), $ErAlO_3$ and natural Apophyllite crystals has been reported [4–9]. The microhardness study of $YFeO_3$ crystals has also been reported [7]. To the best of author's knowledge, there does not seem to be any report on the modifications affected by swift heavy ion irradiation on rare-earth orthoferrite crystals. In the present paper, microhardness studies of 50 MeV Li^{3+} ion irradiated $YFeO_3$ crystals are reported and the modifications affected by the irradiation on the mechanical characteristics of these crystals are discussed.

2. Experimental details

$YFeO_3$ crystals were grown from flux as per the procedure described by Wanklyn [10]. These crystals were then flattened and thinned to their required sizes parallel to (1 1 0) planes as prescribed by the range of the ion irradiation which was calculated using the TRIM/SRIM-98 code. These crystals were then irradiated with a 50 MeV Li^{3+} ion beam at a fluence rate of 1×10^{14} ions $cm^{-2}\,s^{-1}$. The irradiated crystals were used for microhardness measurements at

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Table 1
Results of microhardness measurements for irradiated and unirradiated single crystals of $YFeO_3$

Crystal	$n_k + \Delta n_k$	K_1 (MN m^{-2})	W (N)	K_2 (MN m^{-2})	H_v (MN m^{-2})	$n_h + \Delta n_h$
Irradiated	1.69 ± 0.12	10214	0.046	4637	8599	1.86 ± 0.18
Unirradiated	1.73 ± 0.12	11523	0.041	5639	10457	1.88 ± 0.19

n_k and n_h represents value of n on application of Kick's law ($P = K_1 d^n$) and Hays & Kendall's law ($P - W = K_2 d^2$), respectively $H_v = 1.8544 K_2$.

room temperature (30 °C), using a Vickers microhardness tester (mhp-100) attached to an incident-light microscope Neophot-2 of Carl Zeiss, Germany. Loads ranging from 0.098 to 0.98 N were used for indentation, keeping the indenter at right angles to the crystal plane for 10 s in all cases. The distance between any two consecutive indentations was kept more than five times the diagonal length of the indentation mark in order to ensure that surface effects were independent of each other. Five indentations were made on each surface under examination for the same load and both the diagonals of each impression were measured. An average of 10 diagonal lengths for each load was taken for calculations. The diagonal length of the indentation mark was measured, using a filar micrometer eyepiece at a magnification of 500:1.

The microhardness value H_v was calculated using the formula [11]:

$$H_v = \frac{1.8544P}{d^2} \quad (1)$$

where H_v is the Vickers hardness number, P the applied load and d is the average diagonal length of the indentation mark. The error in H_v was estimated using the expression:

$$\Delta H_v = 1.8544\left[\left(\frac{\Delta P}{Y}\right)^2 + \left(\frac{P\Delta Y}{Y^2}\right)^2\right]^{1/2} \quad (2)$$

where $Y = d^2$, $\Delta y = 2d\Delta d$, ΔP, Δy and Δd being errors on P, Y and d, respectively. A program in Fortran 77, using the method of least squares, was made and run on a computer to calculate the values of various parameters as compiled in Table 1.

Well-defined cracks were considered for the measurement of the crack length and the average crack length of all such cracks was taken for a particular indentation impression. The crack length was measured from the centre of the indentation mark up to the tip of the crack. The unirradiated crystal was also indented and studied to see the modification caused due to irradiation.

3. Results and discussion

3.1. Load dependence of hardness

Fig. 1a is a representative photomicrograph of an indentation impression of an irradiated $YFeO_3$ crystal at an applied load of 0.98 N on the (1 1 0) plane. The indentation impression at the same load and plane in case of an unirradiated $YFeO_3$ crystal is shown in Fig. 1b. The difference in the impressions on irradiated and unirradiated crystals is clearly reflected in the figures.

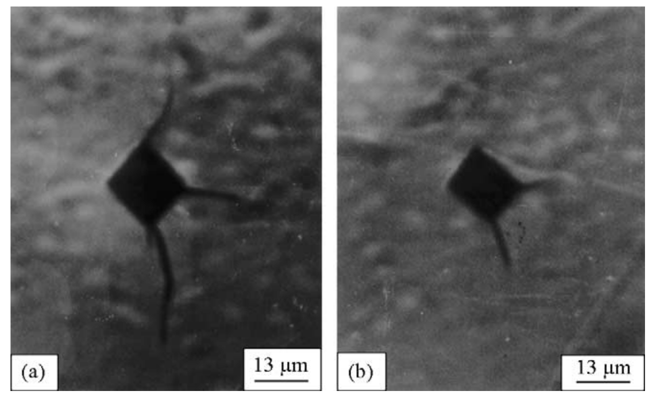

Fig. 1. Photomicrographs of indentation impressions on (1 1 0) planes of flux-grown $ErFeO_3$ crystals at loads of 0.98 N for (a) irradiated (IR) and (b) unirradiated (UIR) crystals keeping the indentation time constant (10 s).

Fig. 2 is a graph showing the variation of the microhardness values with load for the irradiated and unirradiated

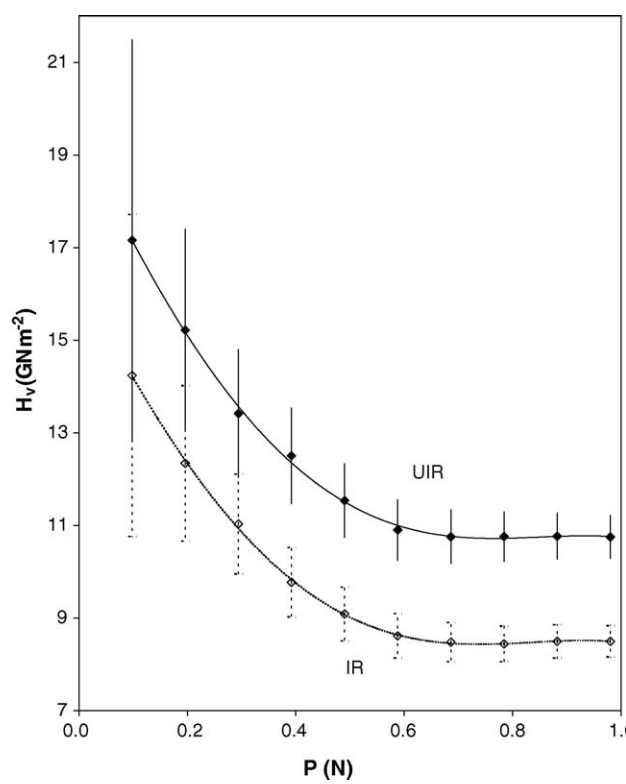

Fig. 2. Graph showing dependence of H_v on applied load for irradiated and unirradiated crystals.