euspen's 17th International Conference & Exhibition, Hannover, DE, May 2017
www.euspen.eu

An investigation into the creep-deformation behavior of KDP crystals using nanoindentation at room temperature

Ning Hou[1], Yong Zhang[1]

[1]School of Mechatronics Engineering, The Harbin Institute of Technology, Harbin 150001, China

Houning3393@163.com

Abstract
It has become a tremendous challenge to manufacture damage-free and smooth surface of KDP crystals to meet the requirement of high-energy laser systems due to its brittle mechanics property. The intrinsic issue is whether KDP crystals have a plastic deformation ability to make KDP remove in ductile mode. This paper investigates the deformation behavior of KDP crystals with the aid of nanoindentation creep at room temperature. Both creep rate and creep depth increase with the increasing peak force and loading rate.

Keywords: KDP crystals; Creep-deformation behavior; Dislocation slip

1. Introduction

Potassium dihydrogen phosphate (KDP) crystals play an important role as optical switching and frequency conversion components in the laser ignition facility of inertial confinement fusion (ICF) [1]. It is crucial for KDP components to own a high laser damage threshold (LDT) to realize the success of ICF. So machined KDP components must have nanometer-roughness surface and damage-free subsurface [2]. To fabricate such stringent KDP surface, the characterization of KDP mechanical property is an importantly fundamental work to invent or select a qualified ultra-precision machining technology. To date, hardness and elastic modulus of KDP crystals have been researched with the aid of microindentation or nanoindentation [3-6]. For example, Tong Fang et al. [3] reported Vickers and Knoop hardnesses and resulting crack on the (100) and (001) planes of KDP crystals. A hardness size effect was observed for the indenting loads in the range of 0.24-1.96 N. These results indicated that comparing with glass and ceramic, the KDP crystal hardness is far lower, but KDP crystals are very brittle. To avoid essentially these problems, KDP crystals need to be removed in a plastic mode. Consequently, an in-depth understanding of the plastic deformation behavior and mechanism of KDP crystals is significant.

2. Experiment

KDP crystals used in this investigation were produced by a rapid growth technology. Nanoindentation creep experiments were carried out on the (001) plane. The mechanical stress cleavage method was employed to obtain a damage-free surface as shown in Figure 1. A piece of KDP crystal was cleaved in parallel to the (001) plane into two parts. The damage-free surface was exposed.

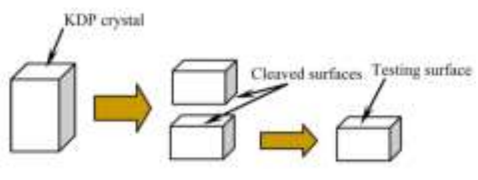

Figure 1. Schematic of the process to obtain a damage-free surface

Nanoindentation creep experiments were conducted on a Hysitron TI950 Triboindenter at room temperature. A standard Berkovich tip with an included angle of 142.35° (the angle from one edge to the opposite side) was used.

Peak forces of indentation from 100 to 8000 μN were applied and the same loading and unloading rates ranging from 20 to 1600 μN/s were used. To examine the creep-deformation behavior of KDP crystals, four holding periods 5, 10, 30, 60 s were applied.

3. Results and discussion

Figure 2 shows the effect of peak force on the creep-deformation behavior when the loading rate is 200 μN/s. Starting points of creep displacement and holding time are aligned to facilitate comparison. The tip area has a nonlinear relationship with the indenter displacement. So a smaller peak force corresponds to a larger contact stress. The large stress can yield a high density of mobile dislocations. The large dislocation density tends to result in a small velocity of dislocation motion, because a lot of network dislocations are introduced. As a result, the creep rate decreases with decreasing the peak force as shown in Figure 2.

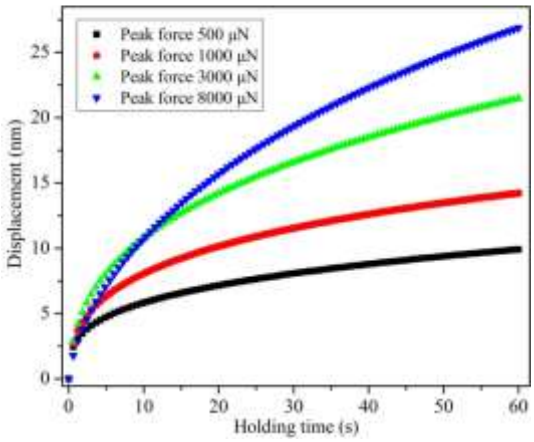

Figure 2. Creep curves under the different peak forces

Figure 3 shows creep curves under the peak force of 8000 μN. It can be seen that the effect of loading rate on creep curve is obvious. The major feature of creep curves is the variation of initial creep rate with loading rate. In this case, the initial creep rate under the loading rate of 1600 μN/s is larger than that under the loading rate of 200μN/s. Because in the beginning of loading, mobile dislocations are injected at increasing rate as the loading rate is increased. But the mobile dislocations are progressively trapped as the creep proceeds. The trapped dislocations result in additional strain hardening and reduce effective stress and dislocation velocity. Thus the creep rates are closer until equal with holding time between the loading rate of 1600 and 200μN/s.

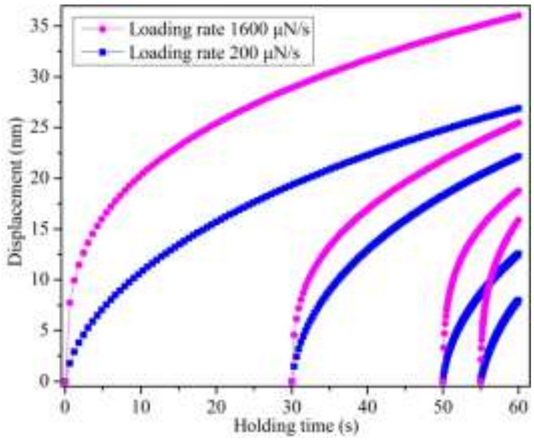

Figure 3. Creep curves under the loading rates of 1600 and 200 μN/s

4. Conclusion

This paper has investigated the creep-deformation behavior of KDP crystals with the aid of nanoindentation at room temperature. The results indicate that KDP crystals can yield a plastic deformation in nano-scale. The creep rate and depth increase with the increasing peak force and loading rate.

References

[1] De Yoreo J J, Burnham A K, Whitman P K. Developing KH2PO4 and KD2PO4 crystals for the world's most power laser[J]. International materials reviews, 2002, 47(3) p 113-152.

[2] Hawley-Fedder R A, Geraghty P, Locke S N, et al. NIF Pockels cell and frequency conversion crystals[C]//Lasers and Applications in Science and Engineering. International Society for Optics and Photonics, 2004 p 121-126.

[3] Fang T, Lambropoulos J C. Microhardness and indentation fracture of potassium dihydrogen phosphate (KDP)[J]. Journal of the American Ceramic Society,2002, 85(1) p 174-178.

[4] Kucheyev S O, Siekhaus W J, Land T A, et al. Mechanical response of KD2xH2(1−x)PO4 crystals during nanoindentation[J]. Applied physics letters, 2004, 84(13) p 2274-2276.

[5] Xiaoguang G, Xiaoji Z, Xianzhao T, et al. Nanoindentation on the doubler plane of KDP single crystal[J]. Journal of Semiconductors, 2013, 34(3) p 034001.

[6] Lu C, Gao H, Wang J, et al. Mechanical properties of potassium dihydrogen phosphate single crystal by the nanoindentation technique[J]. Materials and Manufacturing Processes, 2010, 25(8) p 740-748.