Nanomechanical Properties of Differently Oriented YBCO Thin Films

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Introduction

Microstructural and mechanical properties of YBCO c-axis and <110>-oriented films may provide valuable information to the understanding of the anisotropic superconducting properties of this compound.

In this work, we report on the mechanical properties of c-axis and <110>-oriented YBCO thin films. Conspicuous anisotropy has been observed.

Experimental

Depth-sensing indentation method carried out by AFM (DI Dimension 3100) was used from which the hardness and Youngs' moduli were calculated [1].

Results and Discussion

The hardness (H) and Young's modulus (E) values using [2] where measured to be H=8.5GPa and E = 210GPa for the <001> $SrTiO_3$, while H= 11.0GPa and E=230GPa for the <110> $SrTiO_3$.

SEM inspection of the <110> film's surface reveal granular structures in periodical columnar rows on the {110} plane as depicted in Fig. 1.

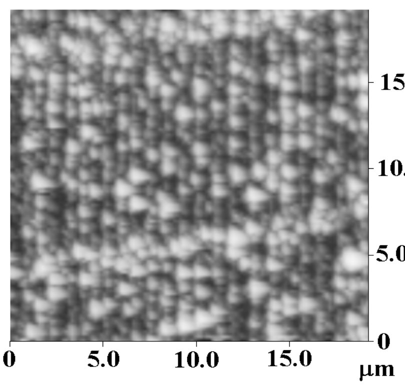


FIGURE 1. AFM image of the <110>-axis oriented YBCO film surface.

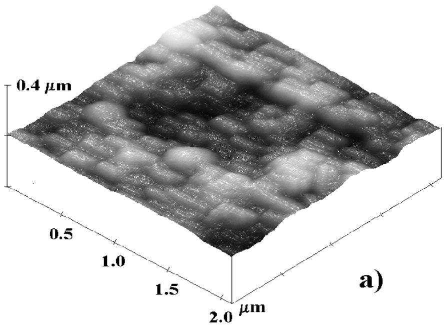
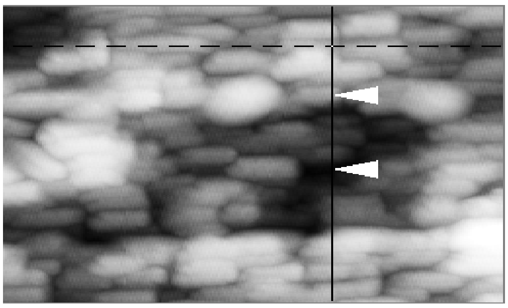
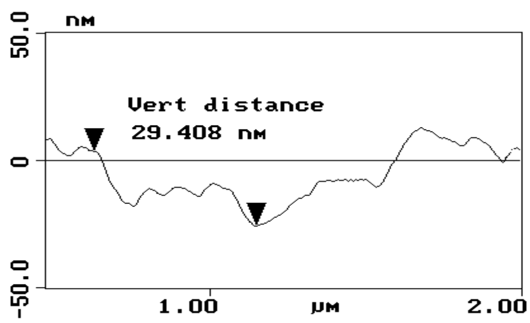


FIGURE 2. AFM 3D image of the <110>-axis oriented YBCO film surface.

The average distance between two nearest rows was measured to be approximately 1µm. The topography of the <110>-axis oriented film shown in fig. 2 is illustrated in fig. 3 (a, b).



a



b

FIGURE 3. a. AFM topography image of the scanned area shown in figure 2**.** b. Its line profile analysis.

We were unable to form any distinctive indent geometry at any load in the <110> films. We could only deduce a rough upper limit of the hardness to be less than 1GPa, which is almost one order of magnitude smaller than that of the c-axis oriented film. Any attempt to scratch the film resulted in tearing grains apart, reminiscent of powder-like behaviors as presented in fig. 4.

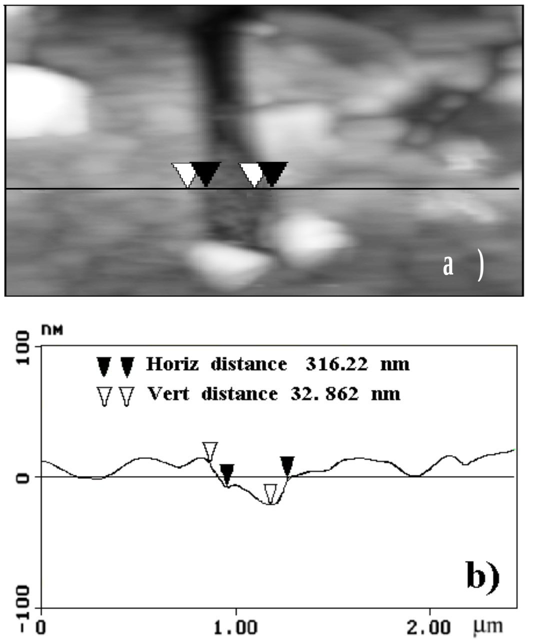


FIGURE 4. AFM Image of a scratch carried out on <110>-axis oriented YBCO film using a load of *P*=10 μN. a) Scratch image. b) Its section analysis**.**

The indent and scratch AFM image suggest an intergrain rather than an intragrain deformation, a behavior, which is expected only in highly elasto-anisotrpic crystals of layered materials such as graphite and mica. A value of approximately 5GPa for the hardness of <110>-oriented films is readily deduced from ref. [2] and ref. [3]. This is inconsistent with our scratching experiments' result which yields a value of 1GPa at most, as described above. In elasto-anisotrpic approach, such discrepancy can be understood via inharmonic bonding forces ignored in this case by neglecting the nonlinear elastic coefficients, which, in principle, can significantly influence the strength anisotropy of layered material

Conclusions

The mechanical properties of YBCO films with c-axis and <110>-orientations were measured. Nanoindentation loading/unloading and nanoscratching techniques were applied to obtain the elastic and hardness properties. Strong anisotropy in mechanical properties was observed.

References

[1] W. C. Oliver and G. M. Pharr, "Measurement of Hardness and elastic modulus by instrumented indentation: Advances in understanding and refinements to methodology," *J. Mater. Res.*, vol. 19, pp. 3-20, Jan. 2004.

[2] P. Kuzel, C. Dugautier and P. Moch, "Comperative study of hypersonic propagation in $YBa_2Cu_3O_{7-\delta}$ single crystals and thin films," . *J. Phys.: Condens. Matter.*, vol. 13, pp. 149-154, Jan. 2001.

[3] M. Lei, J. L. Sarrao, W. M. Visscher, T. M. Bell, J. D. Thompson Migliori, U. W. Welp and B. W. Veal, "Elastic constants of monocrystal of superconducting $YBa_2Cu_3O_{7-\delta}$" *Phys. Rev.*, vol. B 47, pp. 6154-6156, March 1993.