Synthesis, characterization and flux pinning of $\text{YBa}_2\text{Cu}_3\text{O}_y/\text{Y}_{1-x}\text{Pr}_x\text{Ba}_2\text{Cu}_3\text{O}_y$ superlattices*

H.C. Yang^a, L.M. Wang^a, F.F. Lin^b, H.W. Yu^a, H.E. Horng^b, and J.M. Wu^b

^aDepartment of Physics, National Taiwan University, Taipei, Taiwan

^bDepartment of Physics, National Taiwan Normal University, Taipei, Taiwan

Growth, surface morphology and flux pinning of $\text{YBa}_2\text{Cu}_3\text{O}_y/\text{Y}_{1-x}\text{Pr}_x\text{Ba}_2\text{Cu}_3\text{O}_y$ ($x=1$ and 0.5) superlattices were systematically investigated. The superlattices were in situ prepared using an off-axis radio frequency magnetron sputtering system. The x-ray diffraction shows satellite peaks around the main diffraction peaks. The resistivity in the superconducting mixed state shows thermal activated behavior.

Fabrication and characterization of $\text{YBa}_2\text{Cu}_3\text{O}_y/\text{Y}_{1-x}\text{Pr}_x\text{Ba}_2\text{Cu}_3\text{O}_y$ superlattices have received much attention. Most superlattices have been prepared by the pulsed laser deposition¹⁻² and dc magnetron sputtering³ techniques. In this work we report the synthesis, characterization, and flux pinning of $\text{YBa}_2\text{Cu}_3\text{O}_y/\text{Y}_{1-x}\text{Pr}_x\text{Ba}_2\text{Cu}_3\text{O}_y$ superlattices by an off-axis radio magnetron sputtering method.

$\text{YBa}_2\text{Cu}_3\text{O}_y$ and $\text{Y}_{1-x}\text{Pr}_x\text{Ba}_2\text{Cu}_3\text{O}_y$ (PBCO for $x=1$ and YPBCO for $x=0.5$) targets were mounted face to face on a stainless steel chamber. The configuration of an off-axis radio frequency magnetron sputtering system used in this work was the same as that reported in reference 4. The $\text{YBa}_2\text{Cu}_3\text{O}_y/\text{Y}_{1-x}\text{Pr}_x\text{Ba}_2\text{Cu}_3\text{O}_y$ superlattices were in situ grown by depositing the YBCO and $\text{Y}_{1-x}\text{Pr}_x\text{Ba}_2\text{Cu}_3\text{O}_y$ alternatively onto a rotated SrTiO_3 (001) substrates. The superlattices were grown at 720°C with a mixture of Ar and O_2 (3:7) at a total pressure of 300 mTorr. The sputtering power was at 100 watts. After the deposition, oxygen gas at one atmosphere was introduced into the chamber and the samples were cooled to 20°C . The cooling rate was 5°C per minute and the film were maintained at $\sim 620^\circ\text{C}$ for an hour in the cooling process.

The crystal structure of the superlattices was first investigated by the x-ray diffraction. Figure 1 shows the x-ray diffraction pattern near the region of the (001) peak for a YBCO/YPBCO ($120\text{ \AA}/60\text{ \AA}$) $\times 8$ superlattices. In the x-ray θ - 2θ scans for $\text{YBa}_2\text{Cu}_3\text{O}_y$ and $\text{Y}_{1-x}\text{Pr}_x\text{Ba}_2\text{Cu}_3\text{O}_y$ films, only the (00L) ($L=1, 2, \dots, 7$) diffraction peaks were observed, indicating a

c-axis orientation. The presence of the satellite peaks on both sides of the main (001) peak demonstrates the periodic structure in the superlattices.

Figure 1.
X-ray diffraction pattern near the (001) peak for a YBCO/YPBCO ($(120\text{ \AA}/60\text{ \AA})\times 8$) superlattice.

The surface morphology of a $\text{YBa}_2\text{Cu}_3\text{O}_y/\text{Y}_{1-x}\text{Pr}_x\text{Ba}_2\text{Cu}_3\text{O}_y$ superlattices on SrTiO_3 (001) substrate was probed by scanning force microscope. Typically, the average roughness over the scanned area ($1.5\times 1.5\text{ }\mu\text{m}^2$) was about $10.04\text{ \AA}$, indicating a smooth surface of the superlattices.

It has been found that the lower part of the resistive transition in magnetic fields has a thermally activated behavior⁵ described by the following formula:

$$\rho = \rho_0 \exp(-U_0/k_B T),$$

where U_0 is the activation energy which depends on the strength of the magnetic field. Figure 2 shows

*Supported by the National Science Council of R.O.C. under grant no. NSC 85-2112-M003-027PH and NSC 85-2112-M003-014PH

$\log \rho$ vs. T^{-1} for a YBCO/PBCO superlattice ((60 Å/48 Å) × 16) in magnetic fields. The thermally activated behavior of flux motion is clearly demonstrated.

Figure 2
Arrhenius plot of the resistivity as a function of T^{-1} for a YBCO/PBCO superlattice ((60 Å/48 Å) × 16) in varied fields, the increment of magnetic field in each curve is 0.5 T.

Figure 3a
 U_0 as a function of magnetic fields for a series of YBCO/PBCO superlattices, (a) $d_{\text{PBCO}} = 48$ Å and $d_{\text{YBCO}} = 120, 96, 60, 48,$ and 36 Å respectively.

Figure 3 shows U_0 as a function of the applied magnetic field for a series of YBCO/PBCO superlattices. For a fixed thickness of the PBCO layer, the pinning energy of the superlattices increased as the thickness of the YBCO layer is increased. For a fixed thickness of the YBCO layer, the pinning energy of the superlattices decreased as the thickness of the PBCO layer is increased.

Figure 3 b
 U_0 as a function of magnetic fields for a series of YBCO/PBCO superlattices with $d_{\text{YBCO}} = 36$ Å and $d_{\text{PBCO}} = 24, 48, 60, 72$ and 96 Å respectively

In summary, we have in-situ grown $\text{YBa}_2\text{Cu}_3\text{O}_y/\text{Y}_{1-x}\text{Pr}_x\text{Ba}_2\text{Cu}_3\text{O}_y$ superlattices and characterized the superlattice structure of these films. The resistivity in magnetic fields shows thermally activated behavior. The pinning energy of superlattices depends on the thickness of the individual layers. For instance, the flux pinning energy decreased for a series of YBCO/PBCO superlattices with a fixed thickness of the YBCO layer and an increased thickness of the PBCO layer.

References

1. X.D. Wu et al., Appl. Phys. Lett. **56**, 400 (1990).
2. Q. Li et al., Phys. Rev. Lett. **64**, 3086 (1990).
3. J-M. Triscone et al., Phys. Rev. Lett, **63**, 1016 (1989).
4. L.M. Wang, H.W. Yu, H.C. Yang, and H.E. Horng, Physica C, **256**, 57 (1996).
5. T.T.M. Palstra et al., Phys. Rev. B **41**, 6621 (1990).