

## Material Study of High Performance Single Crystal Ferroelectric Nanowires

Yao-Wen Yeh<sup>1,2</sup>, Shiyu Xu<sup>1</sup>, and Nan Yao<sup>1</sup>

<sup>1</sup>. Princeton Institute for Science and Technology of Materials, Princeton University, Princeton, New Jersey 08544, United States

<sup>2</sup>. Department of Electrical Engineering, Princeton University, Princeton, New Jersey, United States

Ferroelectric materials, which exhibit switchable polarization and are piezoelectric, have been extensively studied because of their applications in nonvolatile memory and energy harvesting devices.[1,2] Recently, ferroelectric nanostructures have attracted great interest as they provide a platform to investigate the size effect of ferroelectricity and enable integration with prevailing miniature electronic devices. Characterizations of properties such as piezoelectric coefficient and domain structure are essential to understand nanoscale ferroelectricity and ultimately device integration.[3]

Here, we present the synthesis of one dimensional lead magnesium niobium titanate (PMN-PT) nanostructure via hydrothermal route and its piezoelectric property characterization.[4] The material is of great research value as its magnitude of electromechanical coupling is stronger than the well-known lead zirconium titanate (PZT) and it is structurally more complex than the prototypical barium titanate which allows one to gain more understanding of ferroelectric oxide systems.[5] As shown in Figure 1, typical synthesized nanostructures consist of nanowires with diameters ranging from 200 to 800 nm and length of approximately 5  $\mu\text{m}$ . The composition of the PMN-PT nanostructure was designed to be around the material's morphotropic phase boundary (MPB) as it permits excellent piezoelectric and dielectric properties.[5] The composition (72% PMN and 28% PT) and phase of the nanowires are confirmed by x-ray diffraction and energy dispersive spectroscopy as shown in Figure 2. The potassium contained in the nanowires is caused by the mineralizer potassium hydroxide but does not affect the perovskite phase of the nanowires. In order to study the piezoelectric property of the nanowires, piezoelectric force microscopy was used. The average piezoelectric coefficient ( $d_{33}$ ) of the nanowires was found to be  $375 \pm 5$  pm/V. The value is much higher than the maximum reported values of one dimensional ZnO and PZT nanostructures, which are 26.7 and 130 pm/V, respectively.[6, 7] Recently, the existence of polarization domains has been demonstrated in ferroelectric nanostructures. The understanding of nanoscale domain structure is essential for memory devices since the information is stored in the domain. In order to explore the material's potential applications in miniature memory, our next step is to investigate and manipulate the domain structures in the nanowires with the aid of transmission electron microscopy and PFM.

In summary, we have successfully synthesized high quality single crystal PMN-PT nanowires and characterized the piezoelectric coefficient. While the piezoelectric coefficient of the nanowire is smaller than its bulk counterpart, maintaining the composition near its MPB allows the nanowires to retain a significantly high value of 375 pm/V, which compares favorably to other nanoscale ferroelectric materials.

### References:

- [1] J. F. Scott, *Science* 315, (2007), p. 954
- [2] C. H. Ahn, K. M. Rabe, and J. M. Triscone, *Science* 303 (2004), p. 488
- [3] S. Xu *et al*, *Nano Lett.* 13 (2013), p. 2393

- [4] S. Xu, G. Poirer and N. Yao, *Nano Lett.* 12 (2012), p. 2238  
 [5] S-E Park and T. R. ShROUT, *J. Appl. Phys.* 82 (1997), p. 1804  
 [6] M. H. Zhao, Z. L. Wang, and X. S. Mao, *Nano Lett.* 4 (2004), p. 587  
 [7] Y. Qi *et al*, *Nano Lett.* 11 (2011), p. 1331  
 [8] The work is supported in part by the National Science Foundation-MRSEC program through the Princeton Center for Complex Materials (DMR-0819860).

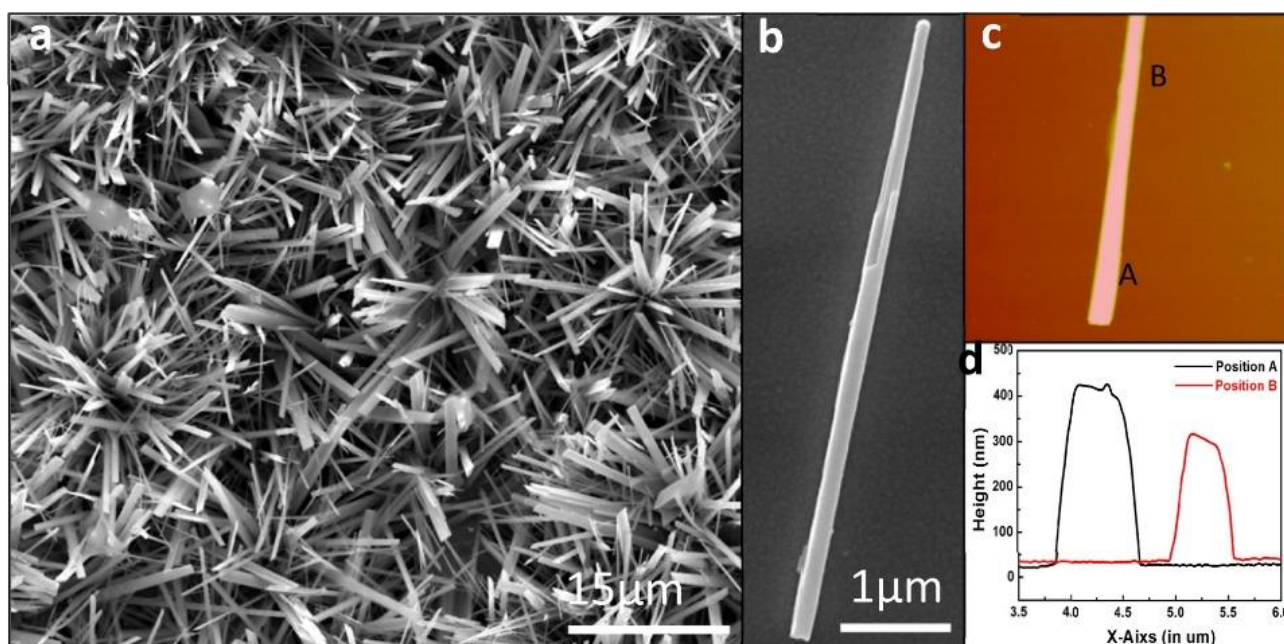


Figure 1: SEM and AFM images of PMN-PT nanostructures. (a) PMN-PT nanostructures consist of nanowires with size ranges from 200 to 800 nm. (b) A single nanowire is about 5  $\mu\text{m}$ . (c) AFM image of a nanowire. (d) Cross-section profile of a nanowire.

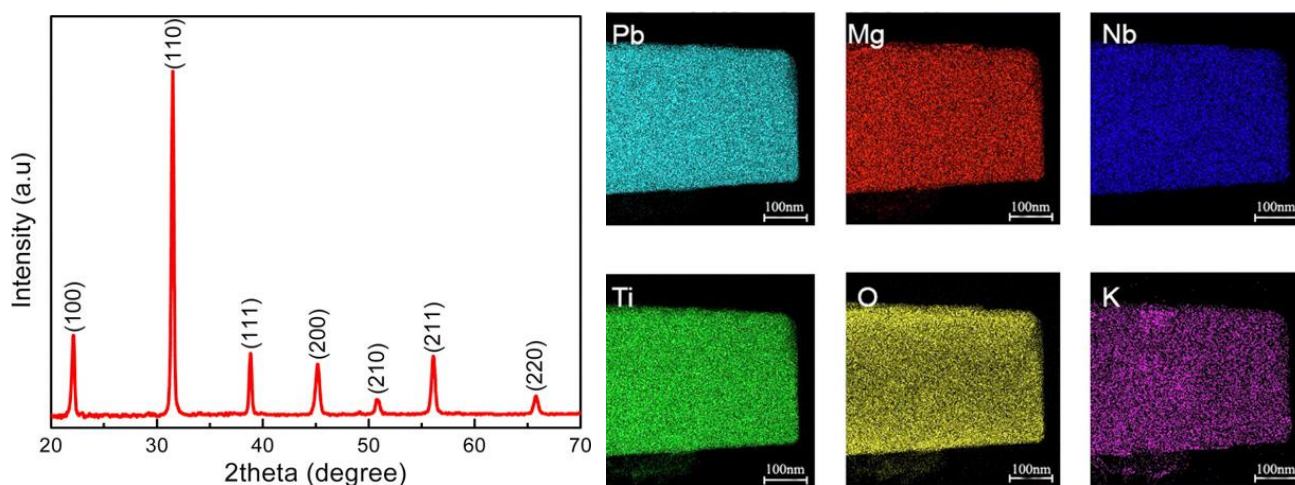


Figure 2: (Left) XRD pattern of the synthesized PMN-PT nanostructures. The diffraction peaks indicate perovskite PMN-PT. (Right) STEM qualitative EDS mapping of a PMN-PT nanowire. Distribution of Pb, Ti, Nb, Mg, O, and K in a nanowire, and a uniform distribution is presented.