Polarization Mapping in Ferroelectric Polymer Thin Films by Pyroelectric Scanning Microscopy

Jingfeng Song*, Haidong Lu, Alexei Gruverman and Stephen Ducharme

Department of Physics and Astronomy, Nebraska Center for Materials and Nanoscience,

University of Nebraska -Lincoln, Lincoln, Nebraska, 68588

Introduction

Polarization imaging based on pyroelectric effect

- Heating the sample an amount ΔT and measuring the evolved charge $\Delta Q = pA\Delta T$
- The thermal pulse technique [1]
- The light intensity modulation method [2,3]

Methods to improve the resolution

- Focus the laser beam[4] or use AFM tip [5]
- Increase the modulation frequency ω base on Thermal Diffusion Length= $\sqrt{2K/\omega}$ [6]

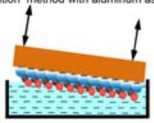
Our Motivation-Optimize both factors to achieve sub-micro resolution

- Use a 405nm blue diode laser with a optimized focus
- Increase the modulation frequency to MHz range

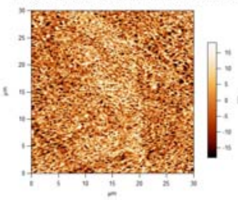
Sample Preparation

P(VDF-TrFE) sample preparation

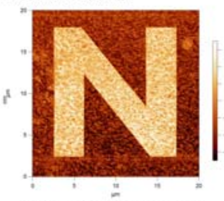
- 25 ML P(VDF-TrFE) 70:30 copolymer was fabricated on Glass substrate using horizontal Langmuir Schaefer deposition method with aluminum as bottom and top electrodes.



- An "N" pattern was prepared on the sample using an AFM tip–poling method[7] and imaged at high resolution by Piezoresponse Force Microscopy (PFM).

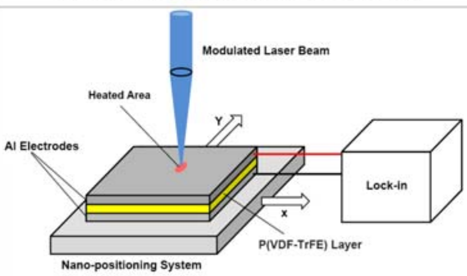


PVDF film topography



PFM image(amplitude×cos(phase))

Pyroelectric Scanning Microscopy Setup



- ❖ A focused blue diode laser (405nm) is applied to heat up the sample.
- ❖ Using Gaussian Beam model the theoretical beam size is 304 nm.

$$2W_0(Beam\ size) = \frac{2\lambda}{\pi \times N.A.} = \frac{2 \times 405nm}{3.14 \times 0.85} = 304nm$$

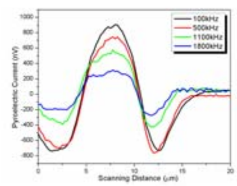
- ❖ The laser is modulated with frequencies varies from 100kHz to 2MHz.
- ❖ The imaging resolution is due to two factors. The laser spot size and the thermal diffusion length.

$$\text{Imaging resolution} \begin{cases} \text{Laser spot size} \\ \text{Thermal Diffusion Length} = \sqrt{2K/\omega} \end{cases}$$

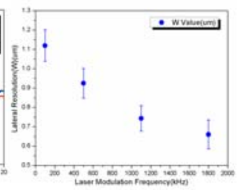
- ❖ Nano-positioning system doing x-y scan with step size varies from 50nm to 250nm.

PSM Results

- ❑ 1-D line scanning along patterned area (white line) with increasing frequency to optimize the resolution.



Line scan result along X direction

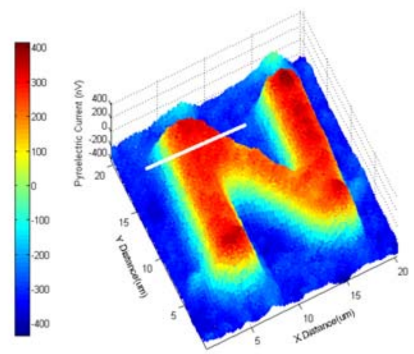


Calculated resolution vs. Modulation Frequency

- ❑ The line scan result across the polarization boundary was first taken a differentiation then fitted by the standard Gaussian function. The standard deviation w is used to describe the resolution.

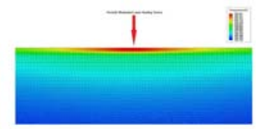
$$F(x) = \frac{1}{w\sqrt{2\pi}} e^{-\frac{1}{2}\left(\frac{x-u}{w}\right)^2}$$

- ❑ The fitting results with different modulation frequencies shows an increasing resolution to submicrometer range.
- ❑ With the optimized focus and highest modulation frequency of 1.8 MHz, a 2-D scanning was applied in the PFM poled "N" pattern.

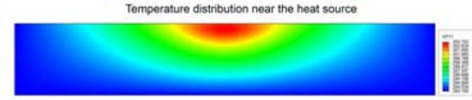


Finite Element Analysis of Thermal Diffusion Process

- ❑ The thermal diffusion process of the laser heat inside the sample is modeled using the Finite Element Analysis Method.
- ❑ The sample is approximated as a 30 um by 5um structure with composite layers of 20nm Al, 40nm PVDF, 20nm Al, and 5um Glass substrate.

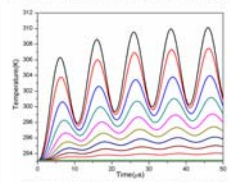


Temperature distribution near the heat source

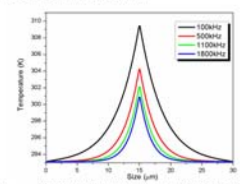


Overall Temperature distribution through out the sample

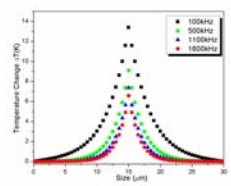
- ❑ With a period heating source, the sample reaches quasi-steady state.



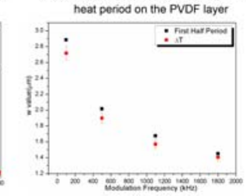
Temperature of the surface center position



Averaged temperature over the first half heat period on the PVDF layer



Averaged ΔT on the PVDF layer in a heating period



The Gaussian fitting results with increasing frequency

Computational Results

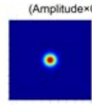
- ➢ The imaging process and results were simulated with convolution method using Matlab®

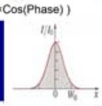
$$O(\lambda) = k \int_{-\infty}^{+\infty} S(\lambda_1)\, I(\lambda_1 - \lambda)\, d\lambda_1$$

- ➢ O(λ) is the output image, S(λ1) is the PFM image, and I(λ) is the Gaussian function.

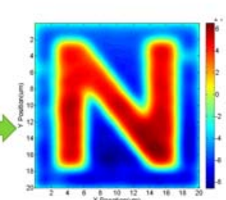
PFM image (Amplitude×Cos(Phase))

Convolution





Gaussian beam with beam size of 304nm



The simulated image

References

[1] R. E. Collins. *Ferroelectrics* **33,** 65 (1981)

[2] S. B. Lang, D. K. Das-Gupta. *Ferroelectrics* **39**, 1249 (1981).

[3] S. B. Lang, D. K. Das-Gupta. *J. Appl. Phys.* **59**, 2151 (1986).

[4] B. W. Peterson, S. Ducharme, V. M. Fridkin, T. J. Reece, *Ferroelectrics* **304**, 51 (2004).

[5] J. Groten, M. Zirkl, G. Jakopic, A. Leitner, B. Stadlober. Phys. Rev. B. **82**, 054112 (2010).

[6] A. Batagiannis, M. Wübbenhorst, J. Hülliger. *Current Opinion in Solid State Mater. Sci.* **14**, 107 (2010).

[7] B. J. Rodriguez, S. J., S. V. Kalinin, J. Kim, S. Ducharme, *Appl. Phys. Lett.* **90**, 122904 (2007).

Acknowledgements

This work is supported by Department of Energy under project NO.DE-FG02-10ER46722 and by Nebraska Center for Energy Sciences Research (NCESR)-Grant NO.26-1217-0001-607 We thank Prof. Mehrdad Negahban and Prof. Ruqiang Feng for providing the FEA software ABAQUS®.

*Email: jingfsong@gmail.com

NEBRASKA CENTER FOR ENERGY SCIENCES RESEARCH