Scanning Probe Charge Reading of Ferroelectric Polarization with Nanoscale Resolution

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ABSTRACT

A scanning probe charge reading technique (SPCRT) that uses a conductive probe tip electrically connected with a charge amplifier device is applied for the detection of electrical charges associated with alternating polarization domains (bits) in a ferroelectric media. High-speed SPCRT is demonstrated by coupling an array of bits (0.8 um wavelength) with a scanning speed of 5.5 mm/s to modulate the bit signal frequency into the 6.9 kHz data rate range. A variant mode of SPCRT implemented with lock-in technique is also demonstrated to read bit charge signals of 80 nm wide polarizations with 10 nm scale spatial resolution.

Keywords: Probe R/W, Charge, Polarization, Ferroelectric, Piezoelectric

INTRODUCTION

The probe storage with an epitaxial ferroelectric $PbZr_{0.2}Ti_{0.8}O_3$ (PZT) recording media [1,2] is a promising technology for a terabyte/inch^2 storage device because a nanoscale and nonvolatile polarization bit may be reversibly written and read by a scanning probe tip. Piezoresponse force microscopy (PFM) [1] is a popular scanning force microscopy (SFM)-based polarization bit reading technique that uses an optical setup of SFM with lock-in technique to enable the detection of piezoresponse motion of ferroelectric polarizations with nanoscale spatial resolution. Compared to PFM, a recently developed scanning probe charge reading technique (SPCRT) [2] uses an exclusively electrical setup comprising a well-established and simple charge-amplifier device to read electrical charges associated with ferroelectric polarizations. In this paper, SPCRT is demonstrated to read bit charge signals with high scanning speeds in a range close to cm/s. A variant mode of SPCRT implemented with lock-in technique is then demonstrated for the first time to read bit charge on PZT media with nanoscale spatial resolution.

SCANNING PROBE CHARGE READING TECHNIQUE (SPCRT)

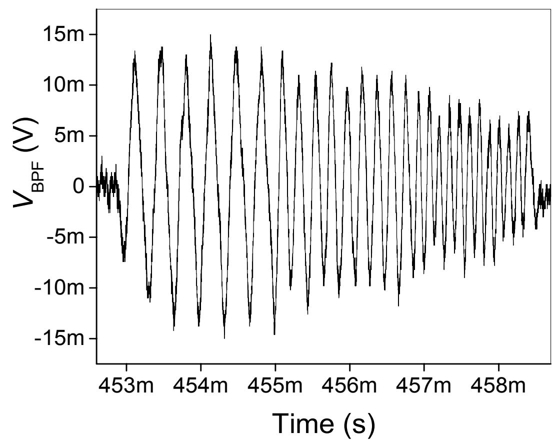

Figure 1: SPCRT bit signal V_{BPF} trace detected with a probe tip scanning at a speed of 5.5 mm/s.

In SPCRT [2], a conductive probe tip loaded with a constant force is in contact with a charge storage recording media, such as the PZT, into which bits represented by up and down polarizations are written with a wavelength. The bit charge is detected upon scanning the probe tip in contact with the polarizations in the media. The tip is electrically connected to a charge amplifier device to detect a charge signal. The charge amplifier converts the charge detected by the tip to a voltage signal. The voltage signal is fed through a bandpass filter to generate a cleaner voltage signal output. An oscilloscope records the bandpass filtered voltage signal, V_{BPF}, profile that reflects the bit charge distribution on the media in the time domain.

Figure 1 is the bit charge signal profile in the time domain generated by scanning the surface of the PZT using the SPCRT. The trace corresponds to three wavelengths of alternating polarization domains; 6 cycles of 1.6 μm wavelength bits, 9 cycles of 1.2 μm wavelength bits, and 12 cycles of 0.8 μm wavelength bits. A probe tip loaded with a contact force of 100 nN was scanned across the bits with a speed of 5.5 mm/s to generate the data of Fig. 1. The three bit wavelengths signal was passed through the bandpass filter (passband of 2-10 kHz, gain of 72 X) that generated the bit signal modulation into the frequency data rate ranging from 3.5 kHz, 4.6 kHz and to 6.9 kHz,

NSTI-Nanotech 2009, www.nsti.org, ISBN 978-1-4398-1782-7 Vol. 1, 2009

respectively for the three bit wavelengths of 1.6 μm, 1.2 μm, and 0.8 μm.

A VARIANT-MODE OF SPCRT

Figure 2 is a schematic test setup of a variant mode SPCRT. A conductive probe tip is in contact with a PZT sample and the sample is vibrated against the tip by a piezo-vibrator. An AC voltage, V_{ac}, is applied to the piezo-vibrator to oscillate the PZT at a reference frequency. The out-of-plane motion of the PZT in contact with the tip generates an alternating piezoelectric charge response at the interface of the tip and PZT. The tip is electrically connected with a charge amplifier thereby detecting a charge signal by converting a charge coupled to the tip from the PZT into an output voltage. A lock-in amplifier selects the output voltage at the reference frequency of the AC voltage to provide clean DC or baseband voltage signal outputs. The lock-in amplifier processes the DC voltage signal into the phase and amplitude of the resulting charge response. An oscilloscope records the bit signal voltage profile that reflects the bit charge distribution on the PZT in time domain.

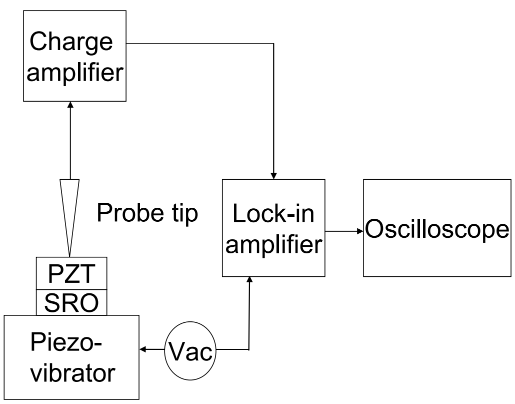

Figure 2: A schematic test setup of a variant mode of SPCRT implemented with lock-in technique

Figure 3 is the phase and amplitude of the resulting bit charge response traces in the time domain generated by scanning the surface of PZT vibrated out-of-plane using the variant mode SPCRT of Fig. 2. The traces correspond to 5 cycles of an 80 nm wide (at 200nm wavelength) pattern of down polarization written over an up-polarization background. A probe tip was loaded with a contact force of 200 nN and scanned across the pattern at 2 μm/s while a 441 kHz AC voltage was applied to the piezo-vibrator to oscillate the PZT with an out-of-plane motion of ~0.3 nm (equating to pressing the PZT with ~3 nN alternating force). The phase signal trace demonstrates a down to up domain boundary transition with 10 nanometer scale spatial resolution.

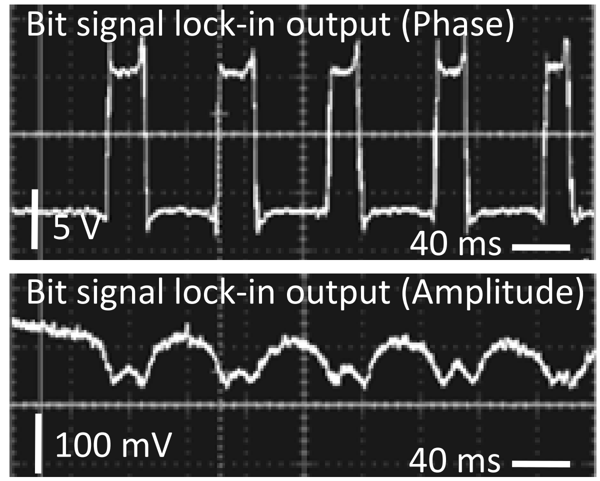

Figure 3: A set of experimental data corresponding to bit charge signal oscilloscope traces obtained using the variant mode SPCRT of Fig. 2; Phase and amplitude signal traces of an array of 80 nm wide down polarizations shown.

SUMMARY

Scanning probe charge-reading techniques have been demonstrated to read local polarizations in a ferroelectric PZT media with high scanning speeds or high spatial resolution. High speed bit charge detection by SPCRT has been achieved by coupling wavelength of alternating polarization with high scanning speed to modulate the bit signal frequency into the upper kHz data rate range. A variant mode of SPCRT implemented with lock-in technique has also been demonstrated to read bit charge signals with nanometer scale spatial resolution.

ACKNOWLEDGEMENTS

The authors are grateful for technical support and/or fruitful discussion with G. Dunbar, B. Stark, W. Hassler, U. Ifiok, N. Franklin, and S. Yang.

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