Measuring 3D pyroelectric distributions with high resolution in thin films by a laser scanning microscope

Cite as: Rev. Sci. Instrum. 94, 023703 (2023); doi: 10.1063/5.0131144
Submitted: 18 October 2022 • Accepted: 7 January 2023 •
Published Online: 6 February 2023

View Online Export Citation CrossMark

D. Smykalla,[1,2,a)] B. Ploss,[1,a)] D. C. Meyer,[3] M. Stelter,[2] and S. Engel[2]

AFFILIATIONS

[1] Department of Scitec, University of Applied Sciences, Carl-Zeiss-Promenade 2, 07745 Jena, Germany
[2] Faculty of Chemistry and Earth Sciences, University of Jena, Humboldtstr. 11, 07743 Jena, Germany
[3] Institute of Experimental Physics, Technische Universität Bergakademie Freiberg, Leipziger Str. 23, 09596 Freiberg, Germany

[a)] Authors to whom correspondence should be addressed: david.smykalla@uni.jena.de and bernd.ploss@eah-jena.de

ABSTRACT

A laser scanning microscope for measuring 3D pyroelectric distributions inside thin vinylidene fluoride-trifluoroethylene copolymer films using the Laser Intensity Modulation Method was developed. The setup consists of a laser unit, a laser driver, an xyz-stepper motor unit, a transimpedance amplifier, and a lock-in amplifier. The focus lens at the laser unit is fixed by magnetic levitation and can correct a defocusing of the system or a tilt of the sample surface. It has been demonstrated in different samples that the system has a lateral resolution of 1 μm for measuring the topological surface structure or the pyroelectric distributions. The self-developed laser driver and transimpedance amplifier combined with a fast lock-in amplifier are able to measure small pyroelectric currents and their variation inside a pyroelectric sample in the range of some 1 pA. The maximum measure frequency of 4 MHz and the fast lock-in make it possible to measure the 3D pyroelectric distributions with high resolution. A 3D scan of 30 different layers with depths of 100 nm–5 μm inside the sample and 100 × 100 points in the xy-direction per layer is performed in 3 days.

Published under an exclusive license by AIP Publishing. https://doi.org/10.1063/5.0131144

I. INTRODUCTION

Pyroelectric thin film materials have found many applications over the last few years. Examples are pyroelectric actuators, micro-energy harvesters, energy-storage devices, IR sensors, etc.[1–5] For the device properties, the polarization distribution inside the films is highly relevant. The polarization distribution can be analyzed non-destructively by measuring the pyroelectric coefficient as a function of frequency. To characterize the distribution inside thin films, the Laser Intensity Modulation Method (LIMM) with a laser as the heating source is an adequate technique.[6,7] When using the LIMM method in a Laser Scanning Microscope (LSM), one of the main challenges is measuring small sample spots. Due to the very small heated spot on the sample surface, the resulting pyroelectric current is substantially smaller than in common LIMM experiments. It is not possible to compensate for this by using a higher laser intensity, as the temperature in the heated spot has to be kept significantly lower than the Curie temperature to avoid depolarization or even destruction of the sample.

To measure samples in the xy-direction Galvano scanners are typically used in LSM.[8,9] They have the advantage of a fast scanning rate, but on the other hand, there are drawbacks due to the limited aperture of the used focus lenses. In the case of an F-theta lens the focus point is moving in a plane, but the minimal focus spot size is 3–30 μm, and it is also not constant over the entire scan field. If a microscope objective is used, the spot size of the laser decreases due to the large numerical aperture and, therefore, the resolution increases close to its theoretical limit (Abbe-Limit). However, in this case, the scan area is limited to less than some 10 μm square, and the resolution will decrease at the edge of the scan area because the focus area is convex. Finally, to achieve a high spatial resolution under the condition of only weak heating of the sample and continuous temperature oscillation at high frequency makes it necessary to use a highly sensitive and low-noise measurement system for the pyroelectric current.

Here we present a high performance cost-efficient system for measuring the polarization distributions of thin films with 1 μm resolution in the xy-direction. In the z-direction, it is possible to

Published under an exclusive license by AIP Publishing