Influence of photoexcitation on the ferroelectric behaviour of ferroelectric-semiconductor-composites

Sebastian Engel[1], David Smykalla,[2] Bernd Ploss[2], Stephan Gräf[1], Frank A. Müller[1]

Sebastian.Engel@uni-jena.de

[1]Friedrich Schiller University of Jena, Otto Schott Institute of Materials Research, Löbdergraben 32, 07743 Jena, Germany
[2]University of Applied Sciences Jena, Department of SciTec, Carl-Zeiss-Promenade 2, 07745 Jena, Germany

Abstract: Ferroelectrics-semiconductor-composites combining piezo-, pyro- and photoconductive properties are investigated. These materials are of particular interest for future applications in the field of small and flexible sensors and actuators.

Keywords: ferroelectrics, semiconductor, polymer, photoconductivity, pyroelectric

Introduction

Our future life will be significantly influenced by e.g. Industry 4.0 and autonomous driving. In this context suitable sensors and actuators have to become smaller and more flexible. For this purpose, ferroelectrics represent an ideal basic material, because of their intrinsic pyro- and piezoelectric properties. However, their simultaneous occurrence prohibits the discrimination between temperature and pressure changes without keeping one parameter constant. This problem can be solved by using a flexible active-matrix cell with a selective poled bifunctional polymer-ceramic composite based on the different curie temperatures of the matrix and the ceramic particles as well as on their different signs of the piezoelectric coefficient [1]. An additional doping of such ferroelectric composites with photoconductive materials like semiconductors enables to expand the sensor properties not only to photosensitivity but also to optimized extraction of the pyroelectric signal power by adjusting its conductivity [2].

Results and Discussion

The present study investigates for the first time the interaction of photoexcitation, polarization and piezoelectricity in composite materials consisting of a non-ferroelectric semiconductor (TiO_2, rutile, $E_g \approx 3.03$ eV) dispersed in both a ferroelectric Poly(vinylidene fluoride trifluoroethylene) [P(VDF-TrFE)] polymer matrix and a composite matrix consisting of polyurethan [PU] and $BaTiO_3$-particles. For both composites, an influence of the photoexcitation on the I-V characteristics was obtained, that depends on its intensity and on the wavelength (Fig. 1a). The occurrence of a maximum conductivity at an excitation wavelength in the range of 415 nm can be explained by a required minimal photon energy combined with an optical penetration depth to generate a charge carrier channel. Furthermore, its remarkable influence on the ferroelectric behavior of both composites is reflected in the hysteresis loops depending on optical excitation. While the measured voltage at the reference capacitor in the case of the P(VDF-TrFE)-TiO_2-composite is not only influenced by the displacement current but also a result of the photo generated current. The photo generated carriers in the PU-$BaTiO_3$-TiO_2-composite enhance the polarization behavior of the $BaTiO_3$particles by saturating the surface charges in the usually insulating matrix [3]. A further influence of the photoexcitation on the ferroelectric behavior of the PU-$BaTiO_3$-TiO_2-composite is illustrated in Fig. 1b. Here, an optical excitation at λ = 415nm leads to an improved coupling of the pyroelectric signal due to the introduction of a tunable direct conductivity (dc) of the matrix σ_m, which increases the imaginary part of the matrix permittivity ε_m [2]:

$$\varepsilon_m = \varepsilon'_m - i\varepsilon''_m - {}^{i}/_{\omega\varepsilon_0}\,\sigma_m$$

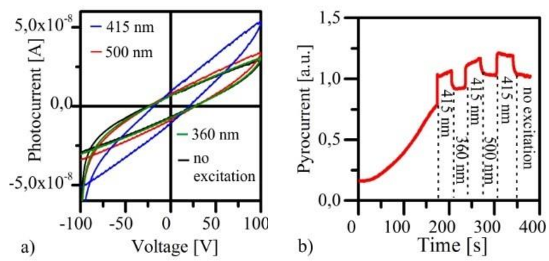

Fig. 1: Properties of the PU-$BaTiO_3$-TiO_2-composite:
a) I-V curves at different excitation wavelength and b) the time dependent pyrocurrent (ΔT=25K) under different photo excitation conditions (0,04 mW/mm^2 for each excitation wavelength).

Conclusions

Beyond the simple combination of piezo-, pyro- and photoconductive properties in one composite our results also demonstrate their mutual interaction. Thus, it is not only possible to optimize pyroelectric sensors by adjusting their conductivity via photo excitation but also to obtain novel actuator designs based on "laser-assisted direct polarization writing" due to optical induced charge carrier transport for surface charge saturation in a normal insulating matrix.

References

[1] I. Graz, M. Krause, S. Bauer-Gogonea, S. Bauer, S. P. Lacour, B. Ploss, M. Zirkl, B. Stadlober, S. Wagner, *J. Appl. Phys.* **2009**, doi: 10.1063/1.3191677
[2] B. Ploss, S. Kopf, *Ferroelectrics* **2006,** 338, 145-151.
[3] B. Ploss, B. Ploss, F.G. Shin, H.L.W. Chan, C.L. Choy, IEEE Trans. on Diel. and El. Ins. **2000**, 7, 517522.

Acknowledgements

DFG is thankfully acknowledged for financial support (MU1803/14-1.)