Fabrication and Testing of Electromechanical Actuation Devices Based on Gd-doped Ceria Thin Films

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Gadolinium-doped ceria (GDC) is the first low dielectric constant / low elastic compliance material to demonstrate a large electrostriction response (so-called non-classical electrostriction) that is competitive with those of commercial electrostrictors. GDC is lead-free and inert with respect to Si, SiO_2 and Si_3N_4, which makes it very attractive as a functional material for a variety of integrated MEMS applications. To this end, we fabricated thin GDC self-supported structures in the form of millimeter-sized membranes, bridges, and cantilevers, using only Si-compatible processes and materials. We monitored structural stability and device electromechanical behavior in response to electric fields of different amplitude and frequency.

The membrane-like structures displayed much higher stability and mechanical robustness than those based on bridges or cantilevers. Regardless of which material was used for contacts (Al, Cr, Ni, and Ti), we found that application of alternating electric field >100k Hz can produce lateral displacement at the membrane center of several μm (at ~10 V). We attribute this behavior to Joule heating, i.e., a thermo-electromechanical response, since the active resistance of the membranes at these frequencies is very low (<1 kΩ) and therefore the power dissipation can be very large (several tens of mW at 10 V). On the other hand, at low frequencies (<100 Hz), membranes with Ti contacts produce observable displacement in the presence of moderately high electric fields (~30 kV cm^{-1}), while membrane structures containing the other contact metals did not provide such functionality. We attribute this difference to the ohmic behavior of the Ti electrodes at room temperature, whereas a blocking layer is formed at the interface between GDC with the other electrode materials. Quantitative measurements of the displacement with atomic force microscope (AFM) at different locations on the membranes revealed a predominantly quadratic dependence on voltage, which is characteristic of electrostriction. Displacement of 500 nm is readily detected with 20Vp-p at 1 Hz, while a much stronger response appears in the lower frequency regime (10-100 mHz). The long relaxation time provides support for our conjecture that the inelasticity of GDC, attributable to the high concentration of point defects, plays a central role in non-classical electrostriction.

Our experimental results confirm our expectation that, with the proper microfabrication protocol and electrode material, GDC may be viewed as a robust and ecologically friendly material for MEMS applications.