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Piezotronic Effect on Electrical Characteristics of Zinc Oxide Varistors

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Abstract : If polycrystalline ZnO is properly doped and sintered under very specific conditions, it shows unique electrical properties, which are indispensable for today’s electronic industries, where it is used as the number one overvoltage protection material. Under a critical voltage, the polycrystalline bulk exhibits high electrical resistance but becomes suddenly up to twelve magnitudes more conductive if this voltage limit is exceeded (i.e., varistor effect). It is known that these peerless properties have their origin in the grain boundaries of the material. Electric charge is accumulated in the boundaries, causing a depletion layer in their vicinity and forming potential barriers (so-called Double Schottky Barriers, or DSB) which are responsible for the highly non-linear conductivity. Since ZnO is a piezoelectric material, mechanical stresses induce polarisation charges that modify the DSB heights and as a result the global electrical characteristics (i.e., piezotronic effect). In this work, a finite element method was used to simulate emerging stresses on individual grains in the bulk. Besides, experimental efforts were made to testify a coherent model that could explain this influence. Electron back scattering diffraction was used to identify grain orientations. With the help of wet chemical etching, grain polarization was determined. Micro lock-in infrared thermography (MLIRT) was applied to detect current paths through the material, and a micro 4-point probes method system (M4PPS) was employed to investigate current-voltage characteristics between single grains. Bulk samples were tested under uniaxial pressure. It was found that the conductivity can increase by up to three orders of magnitude with increasing stress. Through in-situ MLIRT, it could be shown that this effect is caused by the activation of additional current paths in the material. Further, compressive tests were performed on miniaturized samples with grain paths containing solely one or two grain boundaries. The tests evinced both an increase of the conductivity, as observed for the bulk, as well as a decreased conductivity. This phenomenon has been predicted theoretically and can be explained by piezotronically induced surface charges that have an impact on the DSB at the grain boundaries. Depending on grain orientation and stress direction, DSB can be raised or lowered. Also, the experiments revealed that the conductivity within one single specimen can increase and decrease, depending on the current direction. This novel finding indicates the existence of asymmetric Double Schottky Barriers, which was furthermore proved by complementary methods. MLIRT studies showed that the intensity of heat generation within individual current paths is dependent on the direction of the stimulating current. M4PPS was used to study the relationship between the I-V characteristics of single grain boundaries and grain orientation and revealed asymmetric behavior for very specific orientation configurations. A new model for the Double Schottky Barrier, taking into account the natural asymmetry and explaining the experimental results, will be given.

Keywords : Asymmetric Double Schottky Barrier, piezotronic, varistor, zinc oxide
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