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Zinc Oxide Varistor Performance: A 3D Network Model

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Abstract : ZnO varistors are the leading overvoltage protection elements in today's electronic industry. Their highly non-linear current-voltage characteristics, very fast response times, good reliability and attractive cost of production are unique in this field. There are challenges and questions unsolved. Especially, the urge to create even smaller, versatile and reliable parts, that fit industry's demands, brings manufacturers to the limits of their abilities. Although, the varistor effect of sintered ZnO is known since the 1960's, and a lot of work was done on this field to explain the sudden exponential increase of conductivity, the strict dependency on sinter parameters, as well as the influence of the complex microstructure, is not sufficiently understood. For further enhancement and down-scaling of varistors, a better understanding of the microscopic processes is needed. This work attempts a microscopic approach to investigate ZnO varistor performance. In order to cope with the polycrystalline varistor ceramic and in order to account for all possible current paths through the material, a preferably realistic model of the microstructure was set up in the form of three-dimensional networks where every grain has a constant electric potential, and voltage drop occurs only at the grain boundaries. The electro-thermal workload, depending on different grain size distributions, was investigated as well as the influence of the metal-semiconductor contact between the electrodes and the ZnO grains. A number of experimental methods are used, firstly, to feed the simulations with realistic parameters and, secondly, to verify the obtained results. These methods are: a micro 4-point probes method system (M4PPS) to investigate the current-voltage characteristics between single ZnO grains and between ZnO grains and the metal electrode inside the varistor, micro lock-in infrared thermography (MLIRT) to detect current paths, electron back scattering diffraction and piezoresponse force microscopy to determine grain orientations, atom probe to determine atomic substituents, Kelvin probe force microscopy for investigating grain surface potentials. The simulations showed that, within a critical voltage range, the current flow is localized along paths which represent only a tiny part of the available volume. This effect could be observed via MLIRT. Furthermore, the simulations exhibit that the electric power density, which is inversely proportional to the number of active current paths, since this number determines the electrical active volume, is dependent on the grain size distribution. M4PPS measurements showed that the electrode-grain contacts behave like Schottky diodes and are crucial for asymmetric current path development. Furthermore, evaluation of actual data suggests that current flow is influenced by grain orientations. The present results deepen the knowledge of influencing microscopic factors on ZnO varistor performance and can give some recommendations on fabrication for obtaining more reliable ZnO varistors.

Keywords : metal-semiconductor contact, Schottky diode, varistor, zinc oxide
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