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Conduction Mechanisms in Metal Oxide Varistors

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Metal oxide varistors are novel, ZnO-based ceramic semiconductor devices with highly nonlinear current–voltage characteristics similar to back-to-back Zener diodes, but with much greater current and energy handling capabilities. These materials represent a rapidly developing field in the technology of electronic oxide ceramics.

The varistors are produced by a liquid phase sintering process which gives rise to a structure comprised of conductive ZnO grains surrounded by thin insulating oxide barriers. The chemical and physical properties of the phases constituting the resulting 3-dimensional series-parallel junction network will be discussed, and the novel electrical properties interpreted in terms of the material microstructure.

Evidence is presented from a variety of sources to indicate that the thickness t of the intergranular barriers relevant to varistor conduction is $100\ \text{Å} \lesssim t \lesssim 500\ \text{Å}$. The corresponding field F in the intergranular material associated with varistor action is $F \sim 10^6$ V/cm. The highly nonlinear conduction mechanism observed at "breakdown" is consistent with a Fowler–Nordheim type tunneling process obeying a current–density vs field relation given by $J \propto e^{-\gamma/F}$ where γ is a constant. At somewhat lower fields (prebreakdown region) the conduction mechanism follows a thermally activated Poole–Frenkel type law of the form $J \propto e^{-(E_i\beta(F)^{\frac{1}{2}})/2kT}$, where E_i(~1.6 eV) is the ionization energy. Both conduction mechanisms, each dominant for different field–temperature domains, describe a process whereby an electron in a bound state of the intergranular material escapes to the conduction band, where it can contribute to the conductivity. An analysis of the measured current–voltage characteristics of a GE-MOV™ varistor at various temperatures in terms of Poole–Frenkel and Fowler–Nordheim emission is in excellent agreement with the data. The empirical power law behavior $J = (F/K)^{\alpha}$, often used to describe the I–V characteristics, is shown to be a fair approximation to the Fowler–Nordheim relation $J \propto e^{-\gamma/F}$.