Enhance protection of electronic appliances through multivariate modelling and optimization of ceramic core materials in varistor devices

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E-waste comprises discarded low quality protected electronic appliances that annually accumulate million tons of hazardous materials in the environment. Protection is provided to control unwanted voltages that usually generate in associated electrical circuits by a multi-junction ceramic in a voltage dependent varistor. The ceramic’s microstructure consists of ZnO grains that are surrounded by the narrow boundaries of melted specific additives such as Bi$_2$O$_3$, TiO$_2$ and Sb$_2$O$_3$. In fact, the boundaries manage the quality of protection through a certain volume of intrinsic oxygen vacancies transformation which depends on the amounts of the additives. Since these amounts are the ceramic fabrication’s initial input variables, the optimization process is capable of improving the quality of the protection (non-linear coefficient) as an output of the varistor devices. In this work, the fabrication was designed and then experimentally performed to calculate the non-linear coefficients of the produced varistors as actual responses. The responses were used to obtain an appropriate model for the fabrication by different semi-empirical methods. Afterward, the models predicted the optimized amounts of the additives which maximized the quality of the varistors. The predicted condition was fabricated as final varistors that were electrically characterized to compare their nonlinear coefficients as the quality indicator. The comparison demonstrated that the optimized amounts of Bi$_2$O$_3$ (0.5), TiO$_2$ (0.47) and Sb$_2$O$_3$ (0.21) in mol% provided the very high protective varistor with nonlinear coefficients of 28.1. In conclusion, the optimization, which has industrial scale-up potential, warranties the electronic protection that controls global e-waste.

Introduction

Globally, e-waste accumulates millions of tons of hazardous materials such as heavy metals including lead, mercury, cadmium, and halogenated substances into water, soil and air. E-waste comprises discarded electronic appliances, of which anything with a plug (even old refrigerators and motorized toothbrushes) are disproportionately abundant because of their short lifespan. These electronics are often damaged from repeated exposure to large overvoltages which are generated by electrostatic discharge and electrical overstress such as lightning strikes, power outages, tripped circuits, power transitions, power malfunctions, electromagnetic pulses and inductive spikes in an associated circuit. However, the electronics are protected by voltage limiting devices such as voltage dependent low voltage varistors and back-to-back zener diodes that are placed in parallel positions with the electronics in an associated electrical circuit. The problem is that the diodes are degraded by repeated exposure to large overvoltages due to their low capacity and single p–n junction. On the other hand, the varistors tend to be more stable in AC and DC fields over wide ranges of voltage, a few volts to tens of kilovolts, and current from micro-amperes to kilo-amperes. However, the varistors are not sufficiently developed and present several drawbacks such as low non-linear properties, high leakage-current, high breakdown-voltage and high degradation from repeated exposures which come from the microstructure of ceramic cores used in varistors. In the most common varistor, the microstructure consists of highly conductive n-type ZnO grains that are surrounded by the narrow boundaries of melted specific additives. The microstructure is fabricated by mixing an appropriate amount of ZnO and the additives (starting powder). Then the mixed powder is pressed and sintered at a temperature under the melting point of ZnO. Accordingly, the melted...