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Thermally stimulated currents of Zn–Bi–O thin film arresters

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Ceramic varistors based on zinc oxide have excellent properties as protection devices used in power industry. However, their breakdown voltage, dependent on number of grain boundaries, is too high for use in electronic applications. In this work, performance of micro-devices having varistor-type current-voltage characteristics with low breakdown voltage is reported. The thermally stimulated depolarisation current (TSDC) technique was used to study the dielectric relaxation of the Zn–Bi–O thin-film arresters. The surface varistor layers were prepared by r.f. magnetron sputtering on nickel support. The TSDC measuring system and cryostat apparatus used in experiment have been described.

Керамические варисторы на основе оксида цинка обладают отличными свойствами как устройства защиты в энергетической промышленности. Однако их напряжения пробоя, зависящие от количества межзеренных границ, слишком высоки для использования в электронике. В настоящей работе описаны рабочие характеристики миниатюрных устройств, имеющих вольтамперные характеристики типа варисторных и низкие напряжения пробоя. Для исследования диэлектрической релаксации тонкопленочных Zn–Bi–O разрядников применен метод тока термостимулированной деполяризации (ТТСД). Поверхностные слои варисторов получены методом высокочастотного магнетронного напыления на никелевой подложке. Описаны система для измерения ТТСД и криостат, использованные в работе.

Electronic devices with strongly non-linear current-voltage characteristics (varistors) made of zinc oxide (ZnO) were investigated in the USSR already in early fifties of the last century [1, 2]. But a considerable development in this kind of materials for technical applications has been initiated in the seventies of the last century [3]. Up to now, several others, but still very interesting and promising, properties of ZnO are well known and documented, which may find their applications in various technology fields, e.g., in safety devices as sensors of reducing and oxidizing gases [4–6] and, thanks to remarkable optical properties [7, 8], in optoelectronics. That is why the works which focus on technological aspects of various devices (massive, thick and thin-layer) made of ZnO are topical.

In this work, reactive magnetron sputtering process was used to grow films of ZnO. A metallic alloy of zinc and bismuth (with Zn/Bi concentration ratio equal to 9/1) was used as a sputter target. The sputtering process was run in a reactive atmosphere made of oxygen and argon with volume concentration ratio O_2/Ar being varied from 1 to 10. The energy density released at the sputtered target was varied from 4 to 20 W/cm^2. The attained film growth rate was varying from 300 nm/min for pure argon to 10 nm/min for pure oxygen. The films obtained for O_2/Ar volume composition ratio larger than 5 were transparent with slightly yellowish tint. All the obtained layers had strongly non-linear current-voltage characteristics (Fig. 1). The switch-on voltage of the thin-film varistors was varying from few tenths of volt to few volts and the

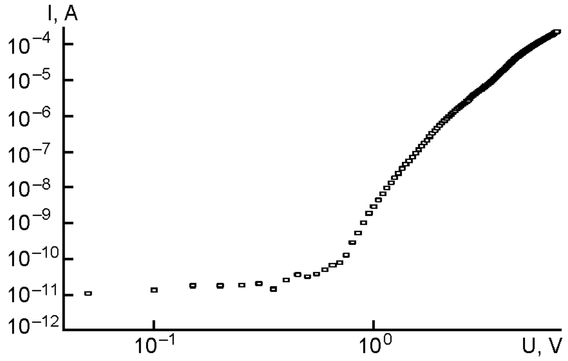

Fig. 1. *I-V* characteristics of thin-film varistors in O_2 atmosphere at room temperature.

non-linearity coefficient α from 5 to 15, depending on the layer thickness.

The *I-V* characteristics of obtained specimens were measured by scanning the DC electric fields at a speed of 0.1 to 1 V/min until the current flowing through the specimens reached 1 mA. These measurements were carried out at room temperature.

The thermally stimulated depolarization currents (TSDC) were measured using short-circuit method [9]. The apparatus set for TSDC measurements is shown in Fig. 2. The cryostat chamber is shown in Fig. 3.

The sample 1 to be examined is placed in cryostat chamber between electrodes 3 and 4 separated electrically by plates cut out of an Al_2O_3 single crystal. Both electrodes are thermally shorted by inertial copper block 5 (being a bottom of tank for cryogenic fluid) with heating coil. The mass of copper block is calculated so as to assure the thermal capacity of the system was sufficient to attain both the stability of the preset temperature (in the range of 100–400 K) in 15 min and cooling the measured sample to liquid nitrogen temperature in 5 min. Electrode 2 is fixed to mobile chuck 6 and thermally shorted by coupling piece 7 with block 6 where the Pt100 temperature sensor 8 is placed.

The TSDC measurements were made in a vacuum (about 10^{-5} Pa), which allows us to measure discharge currents at the noise level ~$5 \cdot 10^{-16}$ A (Keithley 5614 electrometer) in the temperature range of 90 K to 400 K with linear temperature ramp $b = 4$ deg/min for steady thermoelectret formation conditions with formation time, temperature and electric field $t_f = 30$ min, $T_f = 345$ K, and $E_f = 1 \cdot 10^6$ V/m, respectively.

The *I-V* characteristic of Zn–Bi–O thin-film varistors is shown in Fig. 1. All varistors tested exhibited nonlinear *I-V* characteristics. A typical TSDC spectrum of Zn–Bi–O thin-film varistors is shown in Fig. 4. Two characteristic current peaks in the field thin-film varistor TSDC spectrum can be distinguished. The first current peak, α appears within the temperature range of 210 to 230 K (its temperature position is about 225 K). That the α peak seems to be related to the phase transition in the thin-film varistor structure. The next current peak, ρ is caused by a space charge in localised states at ZnO grain boundaries.

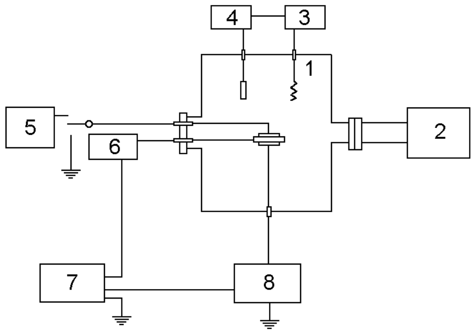

Fig. 2. Schematic diagram of measuring setup for TSDC [10]: 1, measuring chamber (cryostat); 2, vacuum system; 3, temperature controller; 4, temperature programming unit; 5, power supply; 6, reference to cold junctions of thermocouple; 7, personal computer; 8, electrometer.

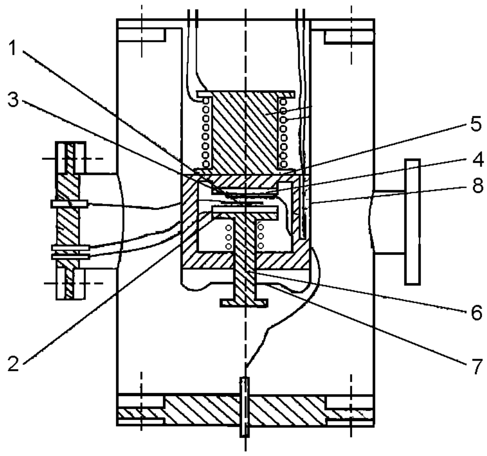

Fig. 3. Cross section of cryostat chamber.

Thus, the shape of *I-V* characteristics measured for thin-film varistor structures allows us to conclude that even in such a simple two-component system, it is already possible to obtain a varistor effect with relatively low breakdown voltage. This is possible when thermal vacuum evaporation of pure metals is used as a deposition process. The TSDC spectrum of the investigated thin-film varistor shows presence of two peaks. These peaks are connected with phase transition of investigated material and space charge type depolarisation. Additional investigations will be carried out.

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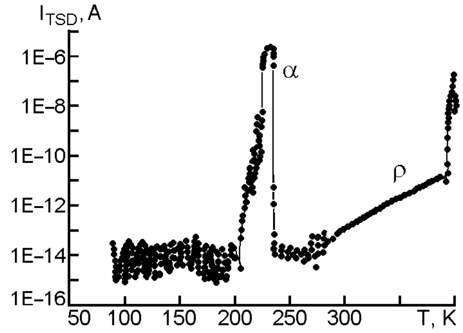

Fig. 4. TSDC spectrum for Zn–Bi–O thin-film varistor.

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Термостимульовані струми в тонкоплівкових Zn–Bi–O розрядниках

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Керамічні варистори на основі оксиду цинку мають відмінні властивості як пристрої захисту в енергетичній промисловості. Проте їх напруги пробою, які залежать від кількості міжзеренних границь, є надто високими для застосування в електроніці. В роботі описано робочі характеристики мініатюрних пристроїв, які мають вольтамперні характеристики типу варисторних та низькі напруги пробою. Для дослідження діелектричної релаксації тонкоплівкових Zn–Bi–O розрядників застосовано метод струму термостимульованої деполяризації (СТСД). Поверхневі шари варисторів одержані методом високочастотного магнетронного напилення на нікелевій підкладці. Описано систему для вимірювання ТТСД та кріостат, які використані в роботі.