Because of difficulties experienced in the manufacture of resistors based on carbon black and their operating shortcomings, a great deal of research work is being conducted at present with the aim of developing new materials which could be employed as components of the current-carrying elements of variable and fixed volume-type resistors. It has already been demonstrated [1] that most of the requirements for the conducting components of resistance elements can be fulfilled by refractory compounds of transition metals such as nitrides, borides, carbides, and silicides. Use of these compounds in combination with alumina, acting as a dielectric filler, and aluminoborosilicate glass — an effective binder — has enabled resistors to be produced having improved technical characteristics.

Up to now powders composed of particles of irregular shape (after milling) and more than 10-μ size have been employed in the composites investigated. A comparatively narrow range of nominal resistance values (tens of ohms) has been established within which the required service characteristics, in particular temperature coefficient of resistivity (TCR), of resistors are attained. To this range of resistance values there corresponds a certain amount of current-conducting phase (about 50 vol.%). In the resistance layer. Under these conditions the volume of glass binder is sufficient to fill the pores in the rigid skeleton formed by particles of the conducting component and a dielectric filler.

The resistance of an element can be increased by decreasing the volume fraction of the conducting phase in the layer, but this reduces the number of contacts between the conductor particles and sharply increases the TCR of the resistor. However, in this situation it is possible to increase the number of contacts in the layer and hence diminish the dependence of the characteristics of the resistance element on the relative amount of conducting phase by employing very finely divided materials of a regular (cubic or spherical) particle shape.

In the present work a study was made of the possibility of widening the resistance range of resistors by varying the volume proportions of resistance layer components and employing powders produced in low-temperature plasma. As current-conducting phases titanium and vanadium nitrides prepared by the hydrogen reduction of titanium and vanadium chlorides in SHF discharge nitrogen plasma [3, 4] were used. The nitrides were monocrystalline powders of cubic particle shape (Fig. 1) and about 500-Å particle size. They had a specific surface of 15-20 m²/g. The compositions of the powders corresponded, according to results of chemical analyses, to the formulas TiN₀.₈₅ and VN₀.₅₆, with elementary lattice parameters of 4.240 and 4.136 Å, respectively. Their pyenometric densities were 5.20 and 5.70 g/cm³, respectively. Electrical conductivity measurements made on sintered specimens of the titanium and vanadium nitrides at 300°C gave values of 14.5 · 10⁻³ and 7.8 · 10⁻³ Ω·cm, respectively.

The dielectric filler in the composite was alumina produced by oxidation of aluminum powder or anhydrous aluminum chloride in a stream of SHF discharge oxygen or air plasma. Examination of micrographs revealed that the main fraction of the alumina was composed of spherical particles (Fig. 2) of 300- to 700-Å size. The powder had a specific surface of 40-50 m²/g.
Fig. 1. Titanium nitride produced by plasma-chemical method [3], x 150,000.

Fig. 2. Micrograph of alumina produced by combustion of aluminum powder in SHF discharge plasma, x 120,000.

Fig. 3. Micrographs of S-3 glass powder: a) in initial condition; b) after spheroidization in SHF discharge plasma.

X-ray phase analysis established that alumina produced by combustion of aluminum metal powder consisted exclusively of $\gamma$-$\text{Al}_2\text{O}_3$, whereas the products of oxidation of $\text{AlCl}_3$ contained small amounts of the $\delta$ and $\theta$ phases as well as the $\gamma$ modification. To obtain $\alpha$-$\text{Al}_2\text{O}_3$, the powders were calcined for 3-5 h in air at a temperature of 1500°C. The treatment decreased the specific surface of the $\text{Al}_2\text{O}_3$ to 25-30 m$^2$/g. In Table 1 are given the compositions of the impurities found in the alumina powders, which generally corresponded to the compositions of the impurities in the starting materials.

The binding material in the current-conducting elements of resistors was S-3 aluminoborosilicate glass spheroidized in SHF discharge plasma. After being milled in a ball mill, the starting glass powder was composed of irregular-shaped particles (Fig. 3a). It had a specific surface of 1900 cm$^2$/g, an apparent density of 1.8 g/cm$^3$, and a pycnometric density of 3.65 g/cm$^3$. The main fraction of the starting glass powder covered the particle size range 15-75 $\mu$m. Plasma treatment spheroidized the glass particles (Fig. 3b). The spheroidized powder consisted mainly of particles 1-3 $\mu$m in size, and had a specific surface of 7600 cm$^2$/g, an apparent density of 0.5 g/cm$^3$, and a pycnometric density of 3.63 g/cm$^3$.

From these fine powders were produced mixtures with varying amounts of the conducting phase. Current-conducting elements (CCEs) of resistors were shaped by pressing the powders hot on ceramic substrates at a temperature of 1150-1200°C and a pressure of 800 kg/cm$^2$. In Table 2 are given the compositions of the titanium and vanadium nitride composites investigated, the nominal values of resistance of the CCEs of resistors, and the values of TCR of the resistance layers. It will be seen that, by using finely divided titanium nitride as the conducting phase, it proved possible to cover a comparatively wide range of resistance values (1-10$^4$ $\Omega$) without allowing the value of TCR of the resistance element to grow excessively. At the same time, the values of the remaining operating characteristics of the resistors (moisture pickup coefficient, electroaging coefficient, electrical smoothness, etc.) did not exceed the permissible limits.