HIGH-FREQUENCY SINTERING OF MULTILAYER CERAMIC CAPACITORS

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Results of sintering multilayer ceramic capacitors by a high-frequency field are presented. It is shown that half-finished multilayer ceramic capacitors subjected to a high-frequency field are sintered in 5-15 min instead of the several hours taken in the conventional method. Possibilities of using high-frequency fields for sintering ceramic materials and electronic products are discussed.

At present sintering (firing) of half-finished products is the most energy-consuming process in the production of multilayer ceramic capacitors (MCC). Commercial kilns consume a large amount of energy per unit product. This can be explained by the fact that apart from being consumed in sintering half-finished MCC, much energy is spent on heating the thermal insulation and atmosphere in the kiln. An increase in labor productivity and improvement in the working environment require higher material consumption in such kilns, which, in turn, leads to the necessity of developing alternative methods for sintering half-finished MCC and other ceramic materials and electronic products.

Sintering of ceramic materials and products by superhigh-frequency (SHF) and high-frequency (HF) fields is the most promising in this respect [1]. A distinctive feature of HF and SHF sintering of MCC and ceramic materials is that the energy supplied is spent on sintering specimens but not lost in the structural elements [2]. This makes the production more environment-friendly and decreases the power consumption per unit product and the material consumption in the sintering process. Methods and means of protection from exposure to high-power SHF and HF radiation developed at present ensure the safety of operators working with such facilities.

In the present work results of sintering MCC of K10-17 type of the Production Association "Monolit" with various ceramic compositions in a 81.36 MHz HF field are presented. It was reported earlier [3–4] that properties of HF-sintered ceramic materials changed. Therefore, it seems of interest to investigate sintering of MCC with different numbers of metal-doped layers, because a HF field penetrates metals and dielectrics to different depths. In particular, in the case of palladium-doped layers with a conductivity close to that of copper, the penetration depth of HF radiation with a wavelength of 3.75 m is about 4 μm in the metal. Meanwhile, with the most general assumptions, under normal conditions the depth of penetration of HF radiation in a dielectric is of the order of magnitude of the wavelength. Therefore, in the case of an MCC with about ten layers and a thickness of the metal-doped layer of 3 μm, HF radiation penetrates to a depth of 2–3 layers as a maximum, being attenuated by an order of magnitude. Moreover, as was shown by calculations, sintering of 1 g of barium titanate requires 771 J. In this case, with a 10% sintering efficiency for the HF field, the time of sintering of 1 mole of barium titanate is 2–5 min. In this case the absorbed power is defined by the expression

$$P = 0.555 \cdot 10^{-12} f \varepsilon_s E^2 \tan\delta , \tag{1}$$

where ε_s is the static permitivity; f is the frequency of the HF field; E is the strength of the HF field; $\tan\delta$ is the loss tangent of the dielectric. A decrease in the field by an order of magnitude caused by the skin effect in the metal-doped layers results in a decrease in the absorbed power by two orders of magnitude, and because of this

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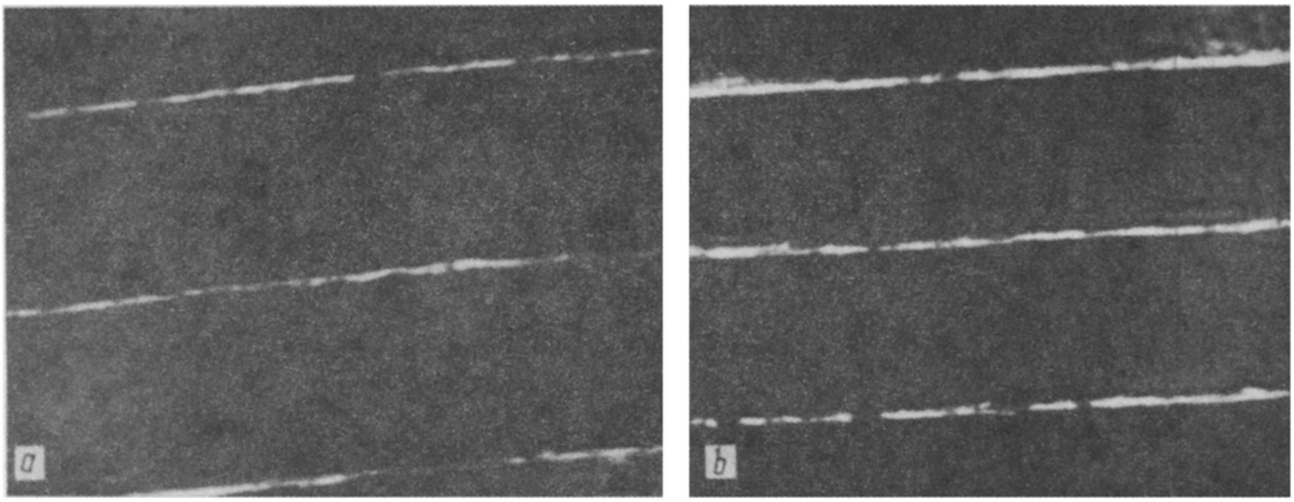

Fig. 1. Structure of K10-17 MCC. Material: a) T-150; b) TNS-2500. ×450.

the inner dielectric layers may not be sintered. In a first approximation sintering of the inner layers by heat conduction can be neglected since because of small sizes of specimens and a short time of sintering, at a sintering temperature of 150 K metal-doped and dielectric layers, having different thermal conductivities, do not distort substantially the sintering process. It can be concluded from the aforesaid that unlike sintering of ceramic materials [3–4], sintering of MCC can follow different mechanisms.

Experiments with sintering of MCC were carried out on a VCD-2.5 setup modified for sintering of ceramic materials. The setup generated 1 kW of vibratory power at 81.36 MHz. Half-finished MCC were arranged on a ceramic support of zirconium dioxide and put into the working zone of the setup. On the support a layer of 50–100 MCC specimens were arranged, which corresponded to 10 g of ceramic material. The time required for sintering this number of MCC was estimated to be 15–20 min, assuming that the MCC were purely ceramic. The experiments revealed that half-finished MCC are sintered in 7–15 min. It appears that the sintering time is independent of the number of metal-doped layers but is determined by the composition of the ceramic material. The measured electric parameters of the MCC were almost the same as the parameters found for MCC sintered by the conventional thermal process. For example, MCC from VS-1 K10-17 material had the following parameters:

a) before moistening: $C = 121$ nF, $\tan\delta \simeq 1.8\%$, $R_{in} = 3 \cdot 10^4$ Mohm;

b) after moistening: $C = 125$ nF, $\tan\delta \simeq 2.0\%$, $R_{in} = 1 \cdot 10^4$ Mohm.

For comparison the parameters will be given for the same MCC produced by thermal firing (the parameters after moistening are given in brackets): $C \simeq 128$ nF (127), $\tan\delta \simeq 2.0\%$ (1.2), $R_{in} \simeq 4 \cdot 10^4$ Mohm ($3 \cdot 10^4$). Here R_{in} is the resistance of the insulation. Temperature measurements have shown that MCC produced by HF sintering fell in the corresponding TCE groups. This fact raises some interest since it was found earlier [3] that in HF-sintered ceramic material VS-1 the permittivity was shifted, although the temperature behavior of $\tan\delta$ was almost the same as that observed after conventional sintering. In Fig. 1 photographs of the structure of MCC of different materials and numbers of layers are shown. It can be seen that the electrodes have no visible breaks and are characteristized by metallic luster. Changes in the electric parameters of moistened MCC suggest their substantial porosity. Consequently, the mechanism of action of a HF field on MCC is different from that involved in the sintering of ceramic materials.

CONCLUSIONS

1. Results of sintering MCC by a 81.36 MHz HF field are given. It is shown that the HF field sinters MCC in 7–15 min instead of the several hours required in conventional sintering.

2. The mechanism of sintering of MCC differs from the mechanism of action of the HF field on specimens without inner metal-doped layers. At present it is difficult to suggest a particular mechanism for sintering MCC.

3. The present studies indicate that HF fields are very promising for firing and sintering ceramic materials with inner metal-doped layers.

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