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Dielectric loss of beta-alumina polycrystalline ceramics of low Na_2O content in 30–200 MHz band

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Polycrystalline beta-alumina with Na_2O content below 5% has been investigated. The ceramic samples have been subjected to X-ray analysis and the electric parameters of the samples determined. The predominance of the α-Al_2O_3 form for ceramics of Na_2O content below 1.7%, and the predominance of the β-alumina form for ceramics of Na_2O content above 2% has been found.

1. Introduction

Using a polycrystalline β-alumina as a sensor in a mechanical–electrical transducer [1] poses different requirements than in the case of applying it as an ion-selective membrane [2–4]. The most essential features are hardness, appropriately selected ion conductivity and good stability during electrical and mechanical measurements.

The need to control the latter parameter turned attention on β-aluminas of less than stoichiometric sodium content and we have been investigating β-alumina and β-bis-alumina polycrystalline pellets with Na_2O content below 5%. Such pellets have been obtained by a diffusion method, introducing Na_2O to α-Al_2O_3 ceramics pellets [5]. The Na_2O quantity introduced was determined by weighing the samples before and after the diffusion process. The initial material was an alundum ceramic, α-Al_2O_3 of density higher than 95% of the theoretical value.

The ceramic samples received have been subjected to X-ray analysis and then the electric parameters of the samples were determined, utilizing among other methods, the Q-metric measurements of the quality factor and capacitance of resonance circuit containing the sample being investigated.

2. Experimental procedure

2.1. *X-ray analysis*

The crystallographic structure of the pellets was determined by an X-ray analysis using the method of turned crystal using a Soviet apparatus 'Dron' 1 (2θ Cu$K\alpha$).

2.2. *Q-metric measurements*

The quality factor and capacitance measurements have been carried out using a resonance method and the Q-meter type UMQL-3 with the investigated sample filling a capacitor included in the LC resonance circuit.

Because of the high conductivity of the samples and resulting low quality factor of the resonance circuit a two-layer structure was used between the capacitor plates: ceramics–air and ceramics–Teflon. A block-diagram of the Q-meter applied is shown in Fig. 1.

The Q-meter used had the following parameters; frequency, 30–200 MHz; quality factor, 30–300; capacitance, 20–80 pF. Using the measured values

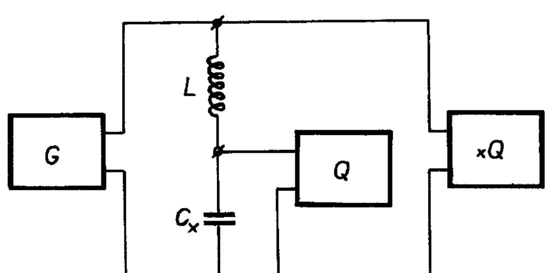

Fig. 1. Block-diagram of the Q-meter. G, generator; L, inductance (measuring coil); C_x, capacitance (measuring and investigated capacitor); Q, voltmeter (quality factor); xQ, voltmeter (quality factor multiplier).

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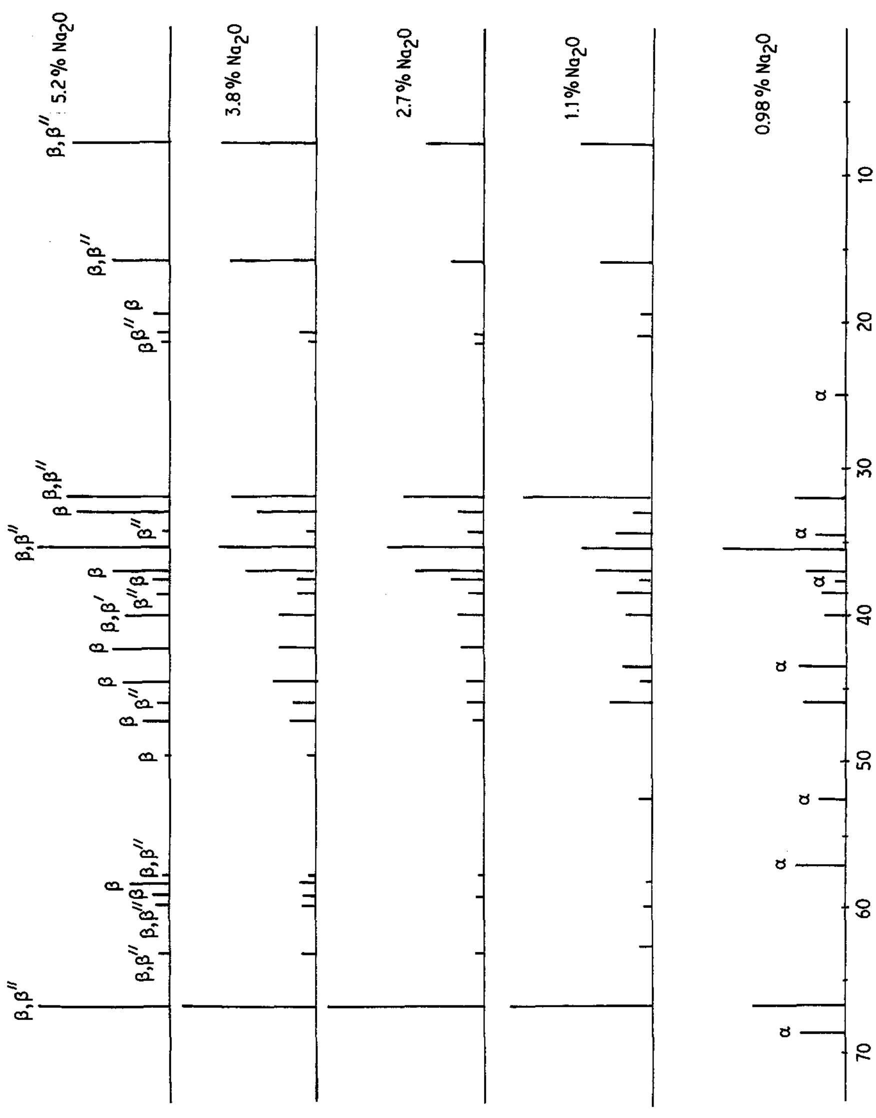

Fig. 2. α-Al_2O_3, β-alumina and β-bis-alumina peak distribution for samples with different Na_2O content.

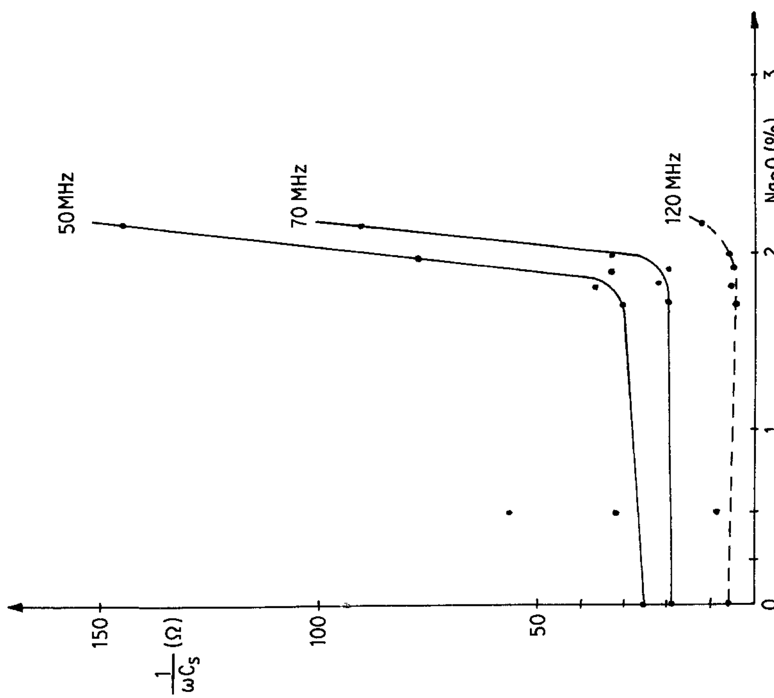

Fig. 4. Dependence of $1/\omega C_s$ as a function of Na_2O content for 50 MHz, 70 MHz and 120 MHz measuring frequencies.

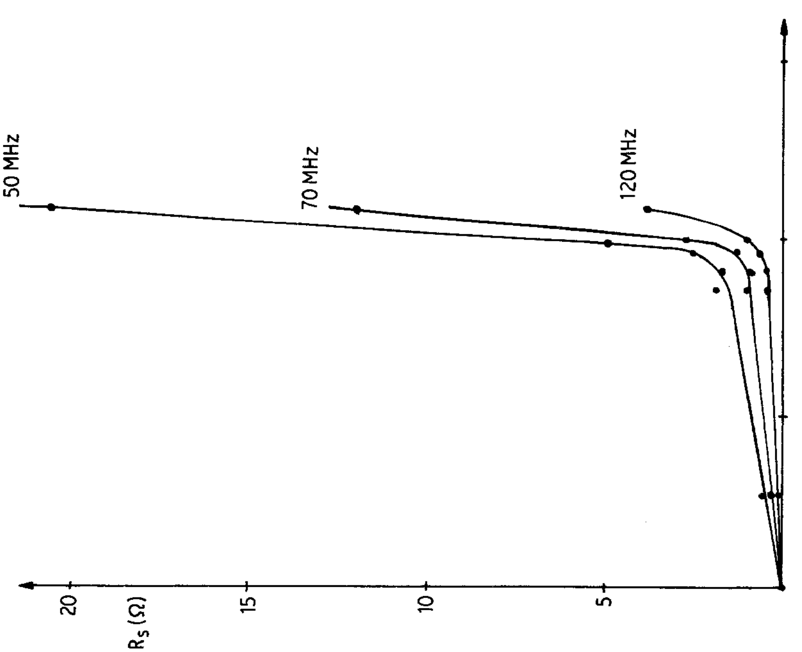

Fig. 3. Dependence of R_s as a function of Na_2O content for 50 MHz, 70 MHz and 120 MHz measuring frequencies.

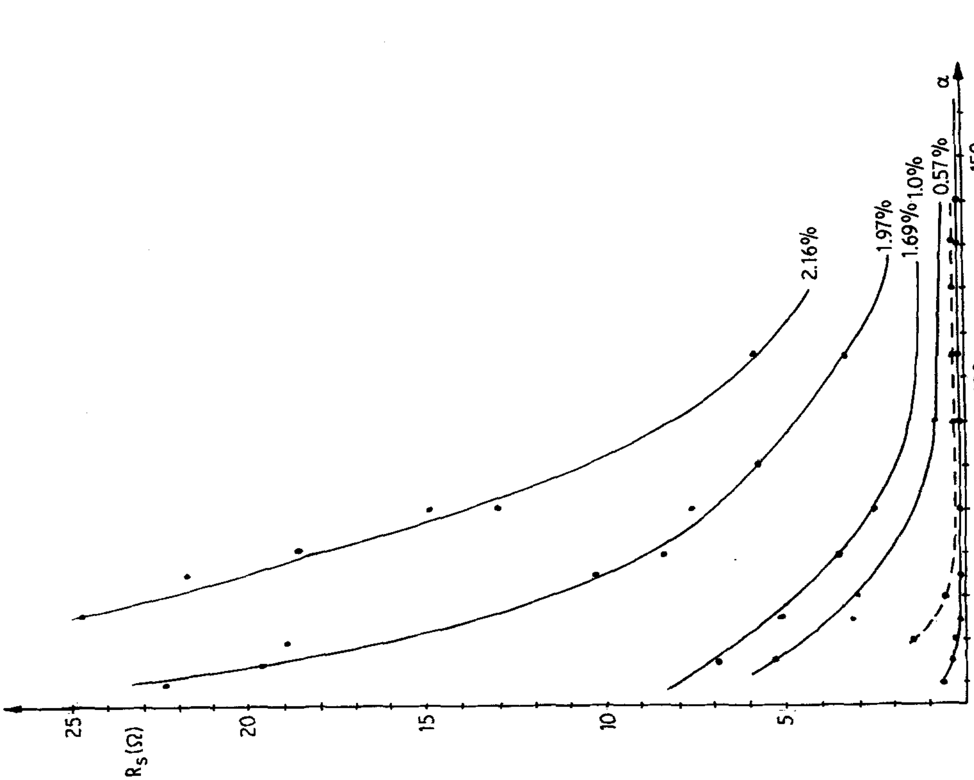

Fig. 5. Dependence of R_s as a function of frequency for β-alumina ceramics with varying Na_2O content.

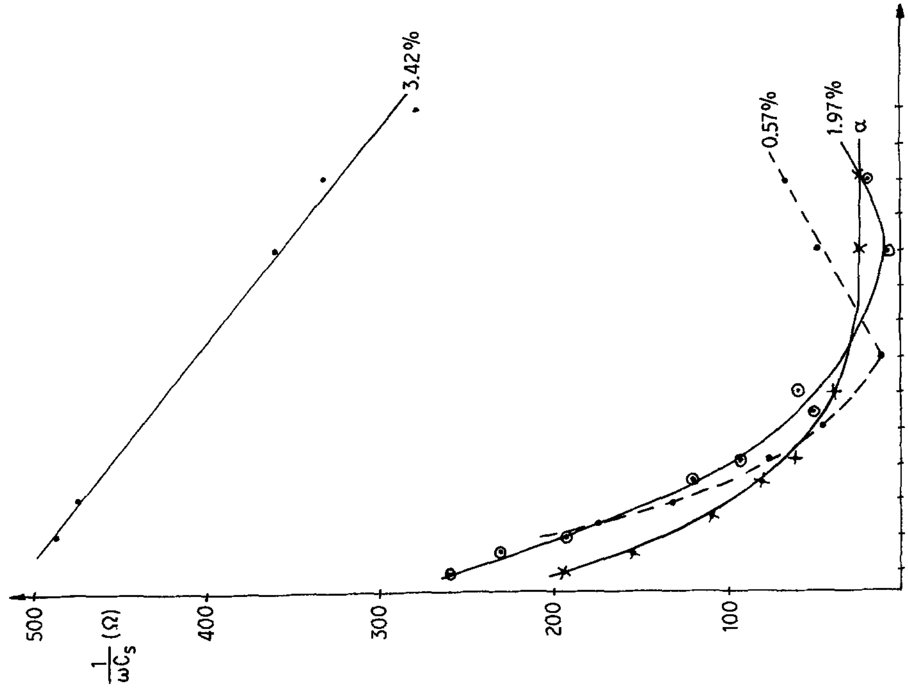

Fig. 6. Dependence of $1/\omega C_s$ as a function of frequency for β-alumina ceramics with different Na_2O content.

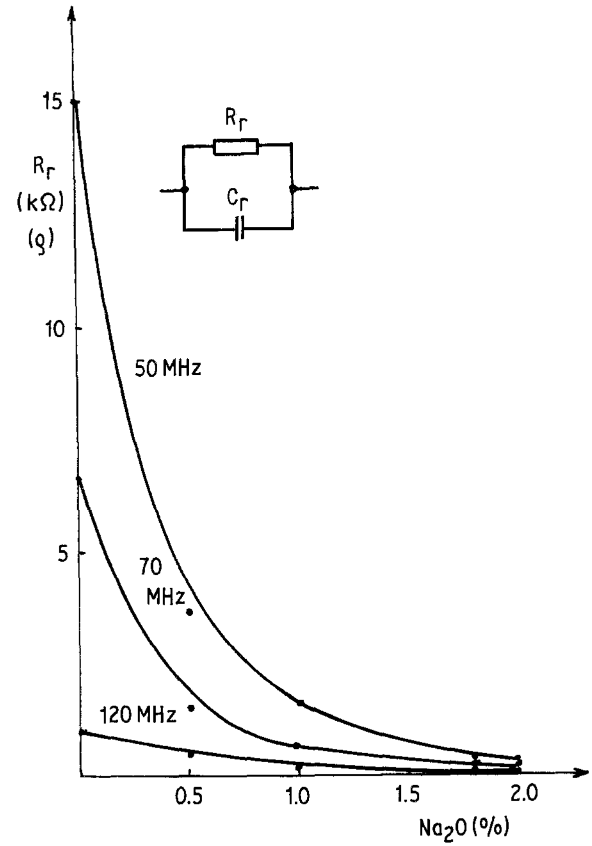

Fig. 7. Dependence of $R_r(\rho)$ as a function of Na_2O content for 50 MHz, 70 MHz and 120 MHz measuring frequencies.

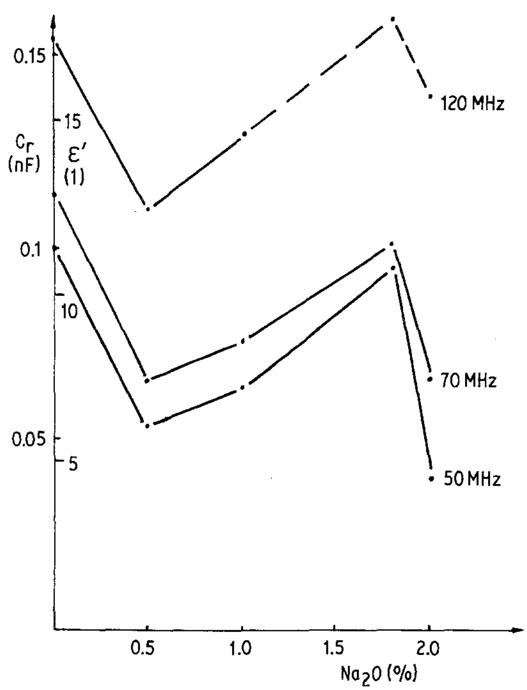

Fig. 8. Dependence of $C_r(\epsilon')$ [1] as a function of Na_2O content for 50 MHz, 70 MHz and 120 MHz measuring frequencies.

of capacitance, quality factor and geometric parameters of the capacitor containing the investigated sample the parameters of a R_sC_s series circuit, equivalent to the investigated β-alumina sample in both frequency response and Na_2O content, were calculated.

3. Results

Typical X-ray photographs of β-alumina pellets with different Na_2O content are shown in Fig. 2.

For ceramics of Na_2O content lower than 0.7% an α-Al_2O_3 form is dominating.

Ceramics of Na_2O content ranging from 0.7% to 1.7% are mixtures of alpha, beta-bis and beta forms. Some relative peak intensities for the beta form are too high which suggests deformation of the β-alumina crystallographic structure.

For ceramics of Na_2O content above 1.7%, the alpha form does not exist and the deformation of the β-alumina structure disappears [6–7].

The Q-metric measurement results after recalculation into R_s and $1/\omega C_s$ for an equivalent electric series circuit are shown in Figs. 3–6.

The dependences $R_s = \phi$ (%Na_2O) and $1/\omega C_s = \psi$ (%Na_2O) at constant frequencies indicate the presence of two distinctly different regions. For ceramics of Na_2O content lower than 2%, the variations of R_s and $1/\omega C_s$ are small whereas for ceramics of Na_2O content above 2% both R_s and $1/\omega C_s$ increase rapidly.

The frequency dependences of R_s and $1/\omega C_s$ demonstrate that, in the frequency range studied, neither Debay absorption nor resonance absorption is present.

Finally, the parameters of a R_sC_s series circuit after recalculation into R_r and C_r for an equivalent electric parallel circuit are shown in Figs. 7 and 8.

4. Conclusions

Both X-ray analysis and Q-metric measurements demonstrate:

(1) small variations of structure and electric parameters for ceramics of Na_2O content below 1.7%;

(2) a decrease in the importance of the α-Al_2O_3 form and an increase in the deformed β- and β-bis-alumina structure for ceramics of Na_2O content between 1.7% and 2%,

(3) the gradual vanishing of the β-bis form and simultaneous ordering of the beta-alumina structure for ceramics of Na_2O content above 2%.

The research also reveals the possibility of controlling the electric properties of manufactured, β-alumina ceramics and hence the optimization of these properties in order to utilize the mechanical–electrical phenomena.

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