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# Dielectric Properties of $Ba_5Nb_4O_{15}$ Ceramic

By

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***Introduction*** Ceramic dielectrics with high dielectric constant (relative permittivity $\varepsilon_r$) in the microwave frequency range are used as filters, oscillators [1], etc. in microwave integrated circuits (MICs) particularly in modern communication systems like cellular telephones and satellite communications. Such ceramics, known as 'dielectric resonators (DRs)', do not only offer miniaturisation and reduce the weight of the microwave components, but also improve the efficiency of MICs.

DRs chosen for practical applications possess high dielectric constant ($\varepsilon_r > 30$), low loss ($\tan\delta < 2\times10^{-3}$), and small temperature coefficient of resonant frequency ($\tau_f < \pm 20$ ppm/K). In pursuit of high $\varepsilon_r$ materials, a number of ceramics such as $Ba_2Ti_9O_{20}$ [2], $(Zr, Sn)TiO_4$ [3], $Ba(Zn, Ta)O_3$ [4], and $A(B^{3+}_{1/2}B^{5+}_{1/2})O_3$ perovskites [5, 6] have been reported. In the present note, we report preparation, characterisation, and dielectric properties of $Ba_5Nb_4O_{15}$ ($B_5N_4$).

***Experimental*** The material $B_5N_4$ is prepared by the conventional solid state ceramic preparation route. High purity (>99.9%) $BaCO_3$ and $Nb_2O_5$ are mixed in the molar ratio 5:4 in an agate mortar for about 1 h in the presence of acetone. The dried mixture is then calcined in an alumina crucible at 1200 °C for 6 h. The calcined powder is thoroughly ground for 90 min. PVA is added to it as binder and again ground for 30 min. The slurry is then pressed into the form of thick cylinders by applying 1.5 to 2.0 t in a Carver press. The cylindrical pellets are slowly heated to about 200 °C to expel the binder and then sintered at 1420 °C for 4 h. The sintered pellets are polished.

The bulk density of the pellets is measured by the dimensional method. From a thick cylinder one thin disc is cut and powdered. The powder sample is studied using a Rigaku powder X-ray diffractometer. Another thin disc cut from the thick pellet is used as a capacitor by applying silver paste to the faces. The $\varepsilon_r$ and $\tan\delta$ are obtained using an HP 4192 impedance analyser in the range 100 Hz to 10 MHz.

The dielectric constant in the microwave frequency region is measured using the 'dielectric post resonator' method proposed by Hakki and Coleman [7] and later modified by Courtney [8]. The test sample which is in the form of a cylinder, $D/L \approx 2.0$ is placed between two large conducting plates. The $TE_{011}$ resonance is identified using the network analyser (HP 8510 B) as $f_0$. From the sample dimensions $D$ and $L$, and the mode chart given in [7],

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$\varepsilon_r$ is calculated using the formula

$$\varepsilon_r = 1 + \left(\frac{\lambda_0}{\pi D}\right)^2 (\alpha_1^2 + \beta_1^2),$$

where $\lambda_0 = c/f_0$, $c$ being the velocity of electromagnetic waves in free space.

The sample is then placed inside an aluminium cylindrical cavity whose $D$ and $L$ are *approximately 10 times larger than the sample*. The whole set-up is heated slowly using a hot plate. The resonant frequency shift is noted every 10 K, from 25 to 75 °C. A graph is drawn with temperature as abscissa and frequency as ordinate. The temperature coefficient is then obtained from

$$\tau = \frac{1}{f_0}\frac{\Delta f_0}{\Delta T}\ [\text{ppm/K}].$$

The unloaded quality factor ($Q_u$) of the resonator is determined using the stripline method of Khanna and Garault [9]. The resonator is placed symmetrically near a 50 Ω stripline inside a brass cavity of size $6 \times 5 \times 5\ \text{cm}^3$ which serves as shield. From the transmission curve, the width of the $TE_{01\delta}$ resonance, corresponding to the transmission coefficient

$$S_{21u} = S_{21}\sqrt{\frac{2}{1 + S_{21}^2}}$$

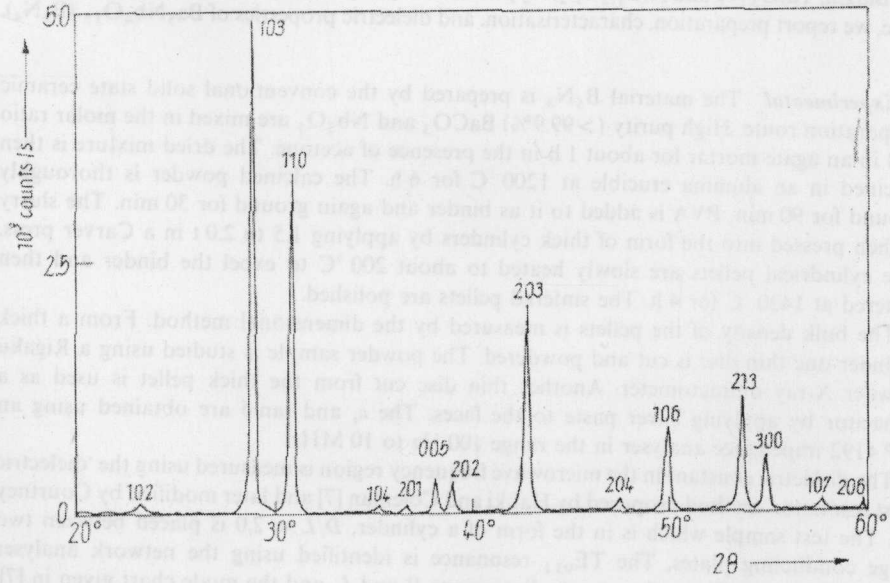


Fig. 1. X-ray powder diffraction pattern recorded from $Ba_5Nb_4O_{15}$ using CuKα radiation

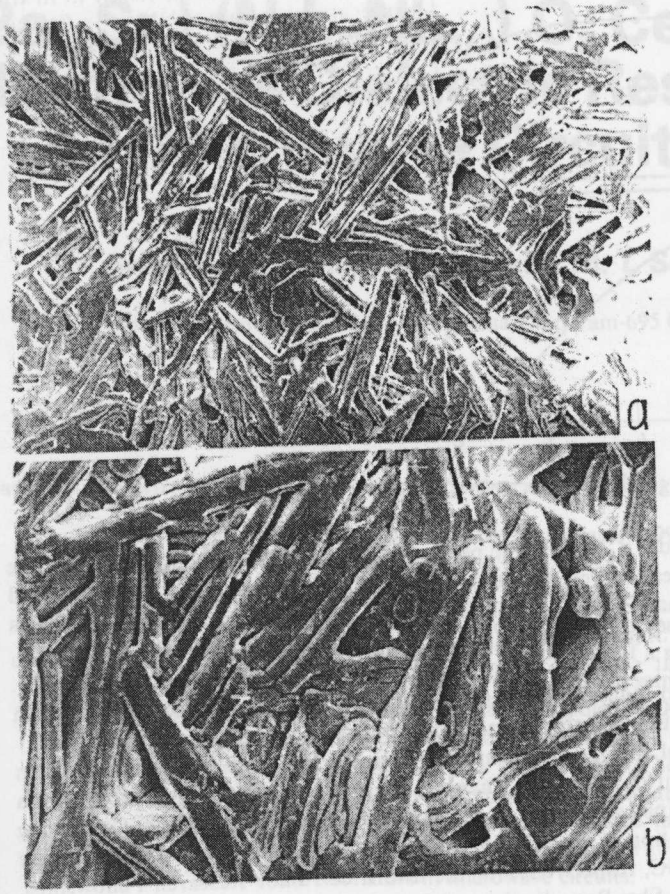


Fig. 2. Scanning electron micrographs recorded from the polished surface of a thermally etched sample

is calculated. If this width is $\Delta f$ and the resonant frequency is $f_0$, $Q_u$ can be calculated using the relation

$$Q_u = \frac{f_0}{\Delta f}.$$

***Results and discussion*** Fig. 1 shows a powder X-ray diffraction pattern recorded from $Ba_5Nb_4O_{15}$. The observed diffraction pattern is in good agreement with JCPDS File No. 14–28. The structure of $B_5N_4$ is hexagonal. The lattice parameters as calculated from Fig. 1 are $a = 0.576$ and $c = 1.177$ nm. The theoretical density is 6.42 g/cm$^3$. The experimental bulk density is 5.9 g/cm$^3$ (92% TD). Fig. 2 shows the microstructure of a sintered pellet recorded after polishing and thermal etching. The variations of $\varepsilon_r$ and $\tan\delta$ in the region 100 Hz to 10 MHz are shown in Fig. 3a and b, respectively.

At 7.2 GHz, the $\varepsilon_r$ obtained is 41.0 and $Q_u > 1.000$. The temperature coefficient of resonant frequency $\tau_f$ is +120 ppm/K.

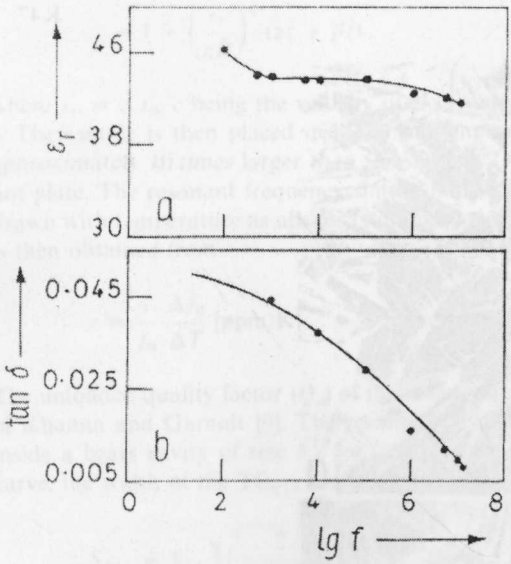


Fig. 3. The dielectric property variation of $Ba_5Nb_4O_{15}$ ceramic in the 100 Hz to 10 MHz range: a) $\varepsilon_r$ vs. frequency, b) tan $\delta$ vs. frequency

*Conclusion* To conclude, $B_5N_4$ ceramic possesses high $\varepsilon_r$ suitable for use as a DR. The relatively large $\tau_f$ precludes its present practical use in high precision devices. Takata and Kageyama [5] reported that $Ba(Nd_{1/2}Nb_{1/2})O_3$ has positive $\tau_f$ and $Sr(Nd_{1/2}Nb_{1/2})O_3$ has negative $\tau_f$. More recently, Sreemoolanadhan et al. [10] prepared $(Ba_{1-x}Sr_x)(Nd_{1/2}Nb_{1/2})O_3$ ceramics and reported that $\tau_f$ can be adjusted to a minimum by varying the value of $x$. Thus, it may be possible to reduce $\tau_f$ by suitable substitution and solid solution formation with similar materials having negative $\tau_f$ and such work is in progress.

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