DIELECTRIC PROPERTIES OF NIOBIUM OXIDE FILM AT ELECTROLYTIC NIOBIUM CAPACITOR

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Abstract: The complex permittivity of the niobium oxide capacitor 4.7 μF was measured at room temperature at frequencies from 20 Hz to 2 MHz using the HP (Agilent) E4980A impedance analyzer, with Agilent 16089C 4-terminal test fixture. Much care was given to proper measurement conditions, to the connection of the tested samples and to setting parameters of the impedance analyzer appropriately with the objective to guarantee the best measuring quality during all tests. The results are frequency characteristics of complex permittivity and comparison with parameters of used dielectric material in tested components, as obtained from the literature.

Keywords: Real part of complex permittivity, imaginary part of complex permittivity,loss number

1. INTRODUCTION

A niobium oxide capacitor consists of a niobium oxide (NbO) anode, an amorphous niobium pentoxide (Nb_2O_5) insulating layer and of a semiconducting manganese dioxide (MnO_2) cathode. The Nb_2O_5 insulating layer is formed electrochemically by anodic oxidation and the thickness of the oxide layer is proportional to the formation voltage with high electric field strength.

The phase diagram of niobium oxide contains three stable components, namely insulating niobium pentoxide Nb_2O_5; there is also conductive niobium monoxide NbO, which is used as an anode, and semiconducting niobium dioxide. Niobium dioxide, if present, is the second main source of defects in the Nb_2O_5 dielectric [1].

Niobium oxide capacitors have been widely accepted in the market; they are lead and halogen free and provide high level of safety and security [2]. They have been designed for new applications such as cellular phones, digital cameras, notebooks and LCD displays.

2. THEORETICAL PART

The loss number (tan δ) or dielectric loss is a measure of the energy loss in capacitor.

$$\tan\delta = 2\pi f C_S R_S = \frac{\varepsilon''}{\varepsilon'} \qquad (1)$$

where ε’ is the real part which represents the relative permittivity and it is equal to

.

$$\varepsilon' = \frac{C_S d}{\varepsilon_0 A} \qquad (2)$$

where C_S is equivalent series capacitance, d/A is constant of the measured capacitor, ε_0 is permittivity of vacuum. And ε” is the imaginary part of complex permittivity:

$$\varepsilon'' = \frac{G}{\omega C_0} \qquad (3),$$

where G is the conductivity , ω is the angular frequency and C_0 is the capacitance of the parallel plate capacitor with free space instead of dielectric.

3. MEASUREMENTS

Niobium oxide capacitors 4.7 μF/10 V_{dc} of the NOJA475M010RWJ type were supplied from AVX Company. The thickness of the oxide layer, as given by the producer, is 84 nm and we obtain the electrode area A = 969 mm^2. Niobium oxide capacitor 4.7 μF was provided with two leads each; samples were soldered with different type of wires to be attached to the Agilent 16089C test fixture, as shown below. In fact what we did in this experiment we change the surface mounted device (SMD), to the lead device, by soldering each 2 samples of niobium oxide capacitors 4.7 μF with two different conducting type of wires, to be able attach it to the 4-terminal Agilent 16089C test fixture

Figure 1: (Agilent) E4980A impedance analyzer with Agilent 16089C test fixture.

The complex permittivity (real part ε’ and imaginary part ε”) were measured using the HP (Agilent) E4980A impedance analyzer, with the 4-terminal Agilent 16089C test fixtures. Values of ε’ and ε” were obtained by VEE Pro Agilent software. Matlab software was used for further calculations made on permittivity and dielectric losses.

Calibration to the standard HP (Agilent) E4980A 20 Hz – 2 MHz impedance analyzer was performed using OPEN and SHORT terminations connected to the test port. Each termination is measured to minimize HP (Agilent) E4980A impedance analyzer inaccuracies; this calibration data is stored in instrument and used in the calculation to suppress errors due to the instrument test fixture and its leads. The measurement of frequency dependence of the niobium oxide capacitor 4.7μF was carried out using AC voltage of 100 mV_{rms} with 5 V_{dc} bias. Fig. 2 shows the real part of the complex permittivity as a function of frequency. The real part of the complex permittivity is 46 at 3 kHz; at low frequencies the real part of the complex permittivity increased significantly to approximately 57 and 56 at 20 Hz for sample 1 and 2, respectively.

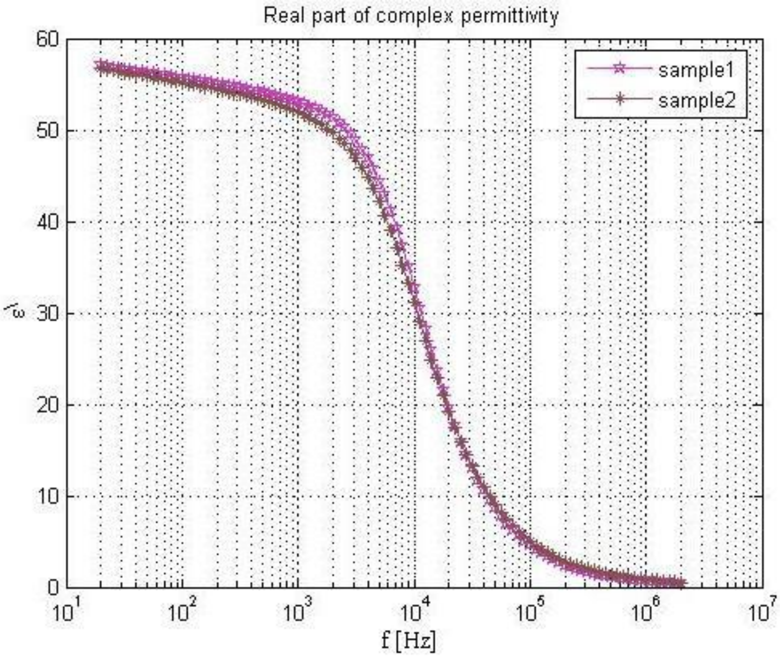

Figure 2: Real part of the complex permittivity .

Fig. 3 shows the imaginary part of the complex permittivity as a function of frequency, one dielectric relaxation was observed at about 10 kHz.

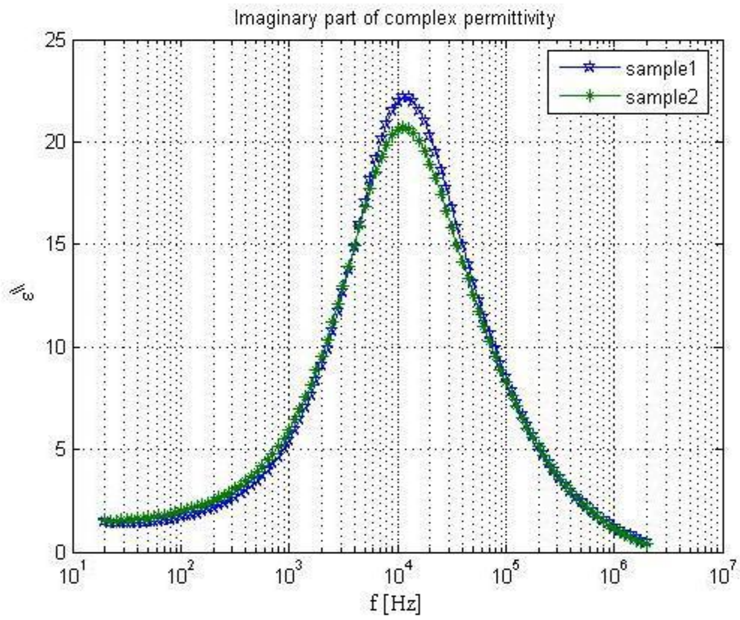

Figure 3: Imaginary part of the complex permittivity .

Fig. 4 shows the loss number (loss factor) of the niobium oxide capacitor for both samples; it is obvious that at low frequencies the ratio between imaginary part ε'' and the real part ε' are approximately the same for both samples. At about 40 kHz the ratio looks different. This will be discussed in more details in the Discussion chapter.

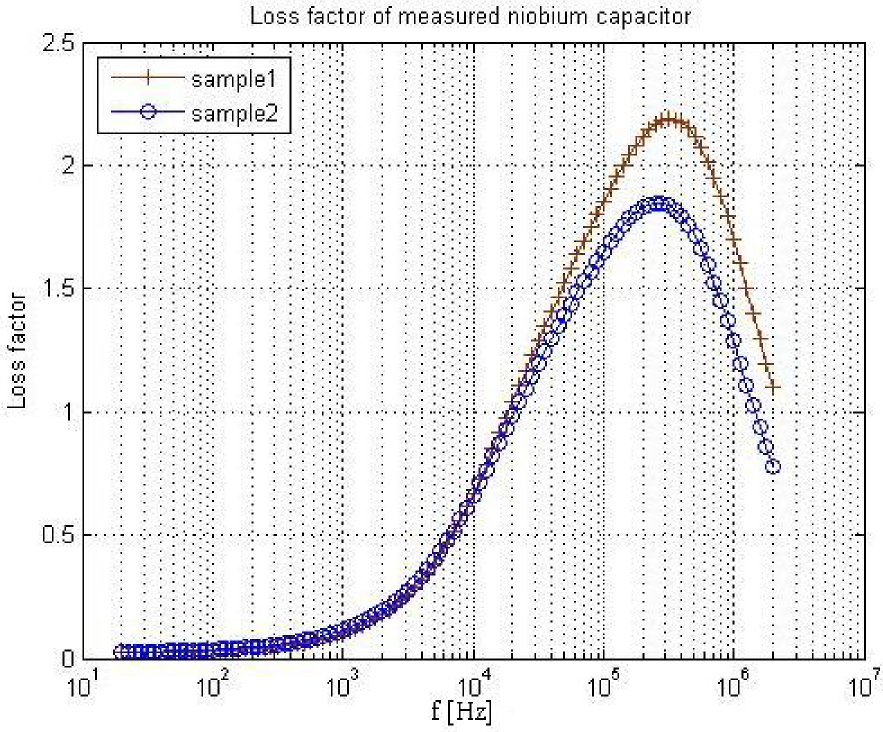

Figure 4: Loss factor of measured niobium capacitor .

4. DISCUSSION

The tolerance of the niobium oxide capacitor 4.7 μF type NOJA475M010RWJ, as given by AVX company, hold at 25 °C and at 120 Hz, is 20% which means (4.70±0.94) μF, The capacitance value indicated by the HP (Agilent) E4980A was 5.8-5.7 μF for samle 1 and sample 2 respectively, above the tolerance, and this due to the soldering the terminals of the niobium capacitor with conducting wires.

If we compare our result with the general features of the frequency dependence of the real part and imaginary part of the complex permittivity for dielectric materials, we get at low frequency the interfacial polarization or space charge polarization. The widths of the relaxation peak is even broadened because there can be a number of conduction mechanisms for the charge accumulating at interfaces, each having its own speed [3].

For the high frequency range see Fig. 2. The real part ε' goes down to zero, where it should not decrease this value as represented in the general features of the frequency dependence of the real part of the complex permittivity for dielectric materials. This is because of two main reasons:

1. Because we soldered the terminals of the niobium capacitor with conducting wires and this causes an increase of the resistance of the device under test electrodes and the contact electrodes of the test fixture, which will result in measurement error [4].
2. The usable frequency limit for 16089C test fixture 4- terminal is low therefore additional errors appears at high frequency range [4].

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