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Temperature dependence of leakage current and noise in Nb_2O_5 films

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Abstract:
Dependence of leakage current on applied voltage was studied for samples of Nb_2O_5 thin films in the wide temperature range from 10 K to 400 K. Simultaneously low frequency noise characteristics and CV characteristics were measured and evaluated. The studied samples were niobium NbO capacitors with Nb_2O_5 insulating layer of thickness about 156 nm. IV characteristics measured for different temperature were evaluated and dominant charge carrier transport mechanisms were determined. The ohmic conduction is dominant for the low electric field. It was found that tunneling current is dominant for low temperatures and electric field higher than 125 MV / m while Poole-Frenkel and Shottky mechanisms are more pronounced for electric field below 125 MV / m and temperature above 350 K. The low frequency noise of 1/f type is observed for the tunneling current while G-R noise is observed in case that P-F and Shottky current is dominant.

INTRODUCTION

A solid state niobium-oxide capacitor is considered as metal - insulator – semiconductor (MIS) structure in which metal electrode consists from niobium-oxide, insulating layer from Nb_2O_5 and semiconductor cathode usually used MnO_2 or conductive polymer CP. The band diagram of the MIS structure was published in [1, 2] for normal mode and reverse mode for samples with MnO_2 and CP cathode, respectively. The potential barriers could be calculated from the IV characteristic of leakage current for normal mode (anode is positive) and reverse mode (anode is negative). Insulating films are prepared by anodic oxidation. This technology leads to the insulator of amorphous structure with high concentration of deep traps. These are oxygen vacancies with concentration of the order of $10^{18}cm^{-3}$ [3]. They act as donors – deep traps which are charged during the electric field application. Before IV characteristic measurement these traps where discharged. Activation energy of these traps is about 0.4 to 0.8 eV depending on the insulating layer preparation [4].
Dominant charge carrier transport mechanisms in the thin oxide films are ohmic, Poole-Frenkel, Schottky and Fowler-Nordheim tunneling mechanisms [5-7]. Ohmic, Schottky and Poole-Frenkel mechanisms are dominant for room and elevated temperature both in normal and reverse mode. For the temperatures below 200 K the dominant charge carrier transport mechanism is tunneling both in normal and reverse mode. For very low temperatures the capacitors could be used as bipolar devices

EXPERIMENT

1. VA characteristic of niobium-oxide capacitors

The experiment was performed with capacitors NC-1803.

The analysis of these characteristics indicates dominant charge currier mechanisms.

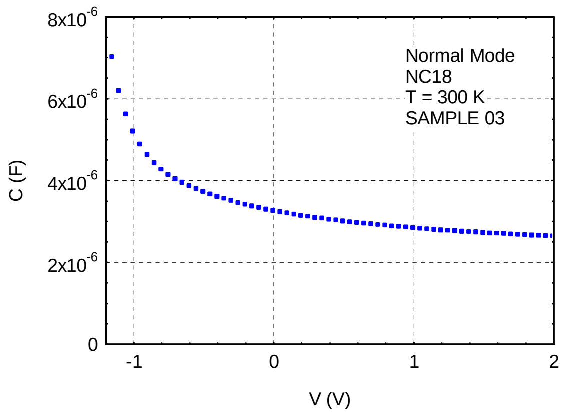

Fig. 1: Capacitance-voltage characteristic of NbO capacitor NC-1803 at the room temperature

CV characteristic of a niobium-oxide capacitor is shown in the Fig. 1. This characteristic is measured at the room temperature. From the measured capacity we have calculated an effective area of electrodes A = 10 cm^2. This value we need for the further calculation of current density in the sample. The dielectric layer thickness was 156 nm. The sample NC-1803 has nominal capacity C = 2.6 μF and rated voltage is 15V for the room temperature.

IV characteristics were measured to analyze conductive mechanism for various temperatures. These are shown in the Fig. 2 for temperature 10 K – 200 K and in Fig.3 for temperatures from 250 K to 400 K. The temperature has big influence of these characteristic and it is obvious that the charge carriers' transport mechanisms are pronounced with different significance. The leakage current increases with temperature in the whole temperature range.

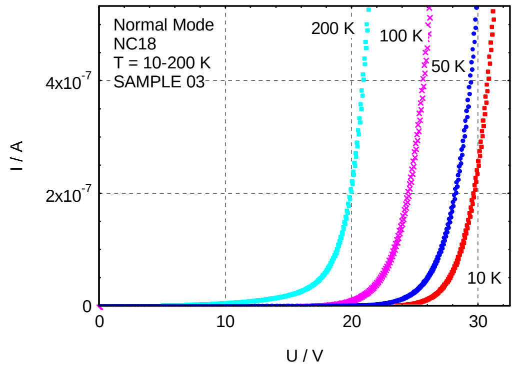

Fig. 2: IV characteristics of niobium-oxide capacitor for wide temperature range in normal mode with increasing temperature from 10 K to 200 K

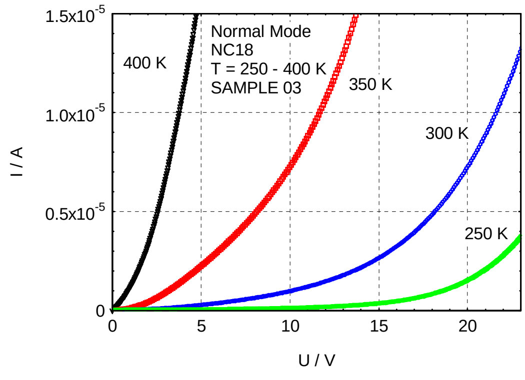

Fig. 3: IV characteristics of niobium-oxide capacitor for wide temperature range in normal mode with increasing temperature from 250K to 400 K

IV characteristics were measured for the normal bias up to 32 V and in the reverse bias up to 4 V depending on the temperature. IV characteristics of NbO capacitor for normal mode and reverse mode are shown in Fig 4 (for T= 200 K and 50 K) and 5 (for T= 400 K and 350 K).

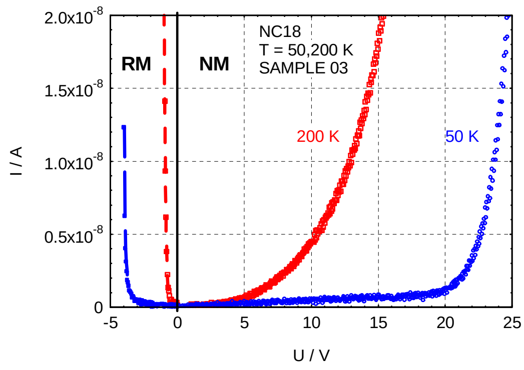

Fig. 4: IV characteristics of niobium-oxide capacitors for wide temperature range for normal mode and reverse mode for T= 200 K, 50 K

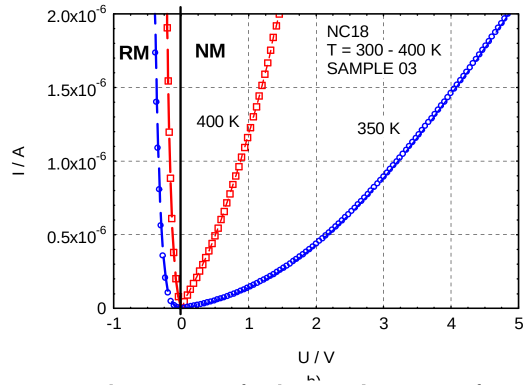

Fig. 5: IV characteristics of niobium-oxide capacitors for wide temperature range for normal mode and reverse mode for T= 400 K,350 K

The leakage current in the reverse bias rise rapidly comparing to the normal mode curves. The capacitor is possible to use up to 4 V on the temperature 50 K as a bipolar device.

The analysis of charge carrier transport mechanism was done using graphical method. The Fowler-Nordheim plot, Poole-Frenkel plot and Schottky plot are shown in Fig. 6 - 7. In Fig. 6 the Fowler-Norheim plot for 10 and 50 K is given.

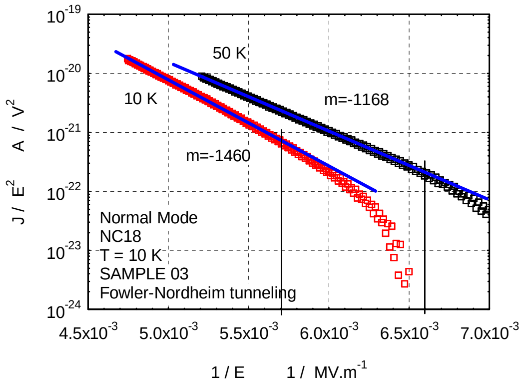

Fig. 6: Fowler-Norheim plot for temperature 10k and 50 K for normal mode

We can see the tunneling current is dominant from the electric field 175 MV/m for the temperature 10 K and 150 MV/m for the temperature 50 K. In Fig. 7 the Fowler-Norheim plot for temperatures 250 and 300 K is given. We can see the tunneling current become dominant from the electric field 125 MV/m both for the temperature 250 K and 300 K. It is shown tunneling current component as dominant mechanism for low temperatures. We can see that for temperature above 250 K the leakage current value is higher than the expected contribution of the tunneling component (represented in the figure by the solid blue line). This we suppose is the contribution of Schottky current component and Poole-Frenkel current component.

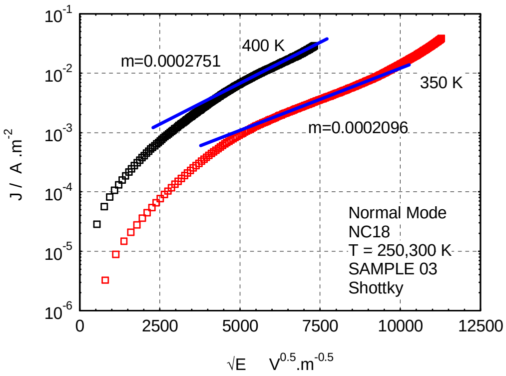

Fig. 7: Schottky plot for higher temperatures from 350 to 400 K for normal mode

2. Low frequency noise in capacitors

The low frequency noise was measured for the sample NC-1803. The voltage noise spectral density for temperature 350K is shown in Fig. 8. The lower line represents the measuring set-up background, the higher is the dependence measured for the voltage 12 V on the sample. The voltage noise spectral density is 1/f type as we expect for high electric field on the sample. Ohmic current component and Poole-Frenkel current component are thermally activated, while the tunnelling current component is temperature independent in the first approximation.

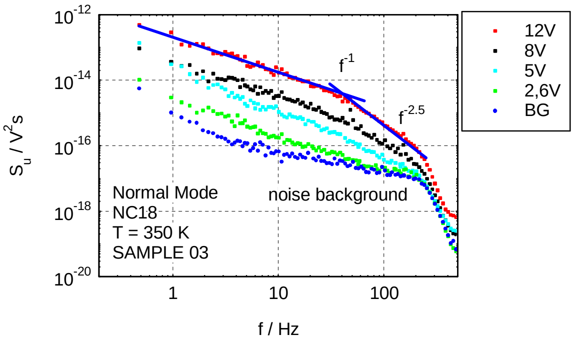

Fig. 8: Noise spectral density of NC-1803 for T= 350 K

From the measured noise voltage the voltage noise spectral density S_U was calculated using FFT. The S_I calculated for NC-1803 is shown in Fig. 9 for the temperature 350 K and in Fig. 10 for the temparature 200 K.

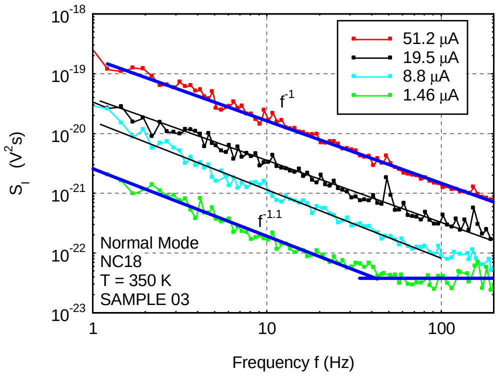

Fig. 9: Noise current spectral density of NC-1803 for temperature 350 K

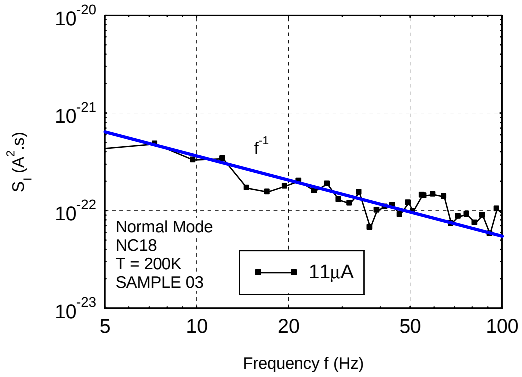

Fig. 10: Noise current spectral density of NC-1803 for temperature 200K in detail

From measured voltage noise spectral density S_U the current noise spectral density S_I was calculated as:

$$S_I = \frac{S_U}{R_L^{\,2}}(1 + 4\pi^2 f^2 R_L^{\,2} C^2) \qquad (1)$$

Where f is frequency and C is the capacity of measured sample, R_L is load resistence in the curcuit and its value is 1 kΩ.

The 1/f noise is observed for the leakage current value above 19 μA for the temperature 350 K. Current noise spectral density is 1/f type for the leakage current value about 10 μA at temperature 200 K, while for the same value of leakage current and the temperature 350 K the current noise spectral density is given by the superposition of 1/f noise and GR noise.

CONCLUSIONS

Measured capacitor has the dielectric layer thickness 156 nm, nominal capacity C = 2.6μF and rated voltage is 15V for room temperature. Calculated effective area of electrodes A is about 10 cm^2.

C-V characteristics for room temperature were measured for our sample. The capacity decreases with increasing voltage in the normal bias, while increases with voltage in the reverse bias.

IV characteristics were analyzed in the temperature range 10 to 400 K both in normal and reverse mode. The capacitor is possible to use up to 4 V on the temperature 50 K as a bipolar device. The analysis of charge carrier transport mechanism was done using graphical method. Fowler-Norheim plot shows that the tunneling current component is dominant mechanism for low temperatures. For temperature above 250 K the leakage current value is higher than the expected contribution of the tunneling component. Poole-Frenkel plot of leakage current shows that Poole-Frenkel current component is dominant in the range 70 to 125 MV/m for the

temperature 300 K and 77 to 125 MV/m for temperature 250 K. The Schottky plot shows that for the temperature 400 K Schottky current component is the dominant one.
Current noise spectral density is 1/f type for the leakage current value about 10 μA at temperature 200 K, while for the same value of leakage current and the temperature 350 K the current noise spectral density is given by the superposition of 1/f noise and GR noise.1/f noise is dominant for high currents for all temperatures, while GR noise, shot noise and thermal noise (current noise spectral density is of Lorenzian type) are observable for low current values mostly for temperatures higher than 200 K. For the current, where GR noise source is activated, the current noise spectral density is higher, than for higher current which activate 1/f noise only.

ACKNOWLEDGMENTS

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