TEMPERATURE DEPENDENCE OF LOW FREQUENCY NOISE IN TA_2O_5 FILMS

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Abstract: The paper has focused on analysis of noise measurement in Ta_2O_5 insulating films. Tantalum pent-oxide thin films are used as dielectric layers for capacitors. Tantalum capacitors show high relative permittivity, low leakage current density and high reliability. The capacitor is here presented as a MIS structure where cathode is formed by manganese-dioxide (with semiconductor conductivity) and anode is formed by tantalum (with metal conductivity). Capacitor is operated in normal mode when the anode is positive and in reverse mode when the cathode is positive. The measurement set-up allows the low frequency noise and capacity measurements in the wide temperature range. The Ta_2O_5 films of the thickness about 28 nm were examined. The current noise spectral density was analyzed for the temperature range from 10 to 400 K. GR noise and $1/f^a$ noise are observed in the low frequency region with exponent a varying between 1 and 1.5. From the measurement of sample capacity for different temperatures it follows, that the capacity decreases with temperature.

Keywords: tantalum, 1/f noise, Ta_2O_5, GR noise

1. INTRODUCION

Basic charge carrier transport mechanisms observed in the tantalum pentoxide films are: Ohmic, Poole-Frenkel, Schottky and tunneling mechanism [1 to 3]. The contribution of different charge carrier transport mechanisms to the total current depend on the temperature and electric field [4 to 6]. Poole-Frenkel mechanism is dominant for the charge carrier transport in the low electric field bellow 1 MV/cm for the room temperature. This conduction mechanism is thermally activated and it becomes negligible with decreasing temperature. Tunneling of charge carriers through the insulating layer is dominant for the high electric field exceeding 2 MV/cm. Tunneling current is thermally independent in the first approximation. Then the tunneling is the dominant current component observed for the temperatures below 200 K.

For the low electric field the GR noise is dominant in the frequency range 0.1 to 100 Hz at the room temperature [7]. For temperature up to 300K was found current spectral density of *1/f* type. The *1/f* noise is pronounced in the frequency range bellow 10 Hz for higher temperatures, while in the range 2 to 70 Hz GR noise is dominant for low current values. For the insulating layer thickness below 50 nm current noise spectral density is given by the superposition of at least two GR noise components with different time constants. This behavior is observed for the temperature higher than 200 K. Insulating layer prepared by anodic oxidation contains high concentration of defects and then two types of burst noise can be distinguished: i) partial discharges in high electric field and ii) regenerative microbreaks leading to the two state RTS-like noise [8]. We suppose that continuous noise spectrum is due to the fluctuation of polarization.

2. EXPERIMENTAL

2.1. MEASURING SET-UP

The measuring set-up for the noise measurements in the temperature range from 10K to 400K is shows in Fig. 1. Temperature regulation is provided in helium cryostat with vacuum pump. The circuit containing the measured sample C_x and load resistor R_L is located in the cryostat and it is connected through the interferences to the power supply (batteries) and to the measured noise signal pre-amplifier PA15. The pre-amplified signal from the cryostat is filtered (band-pass filter in the range 0.3 to 300 Hz) and amplified by amplifier AM22 and digitalized with the measuring card in computer. The sampling frequency is 1 kHz for our measurements. From the digitalized signal the spectral density is calculated using Fast Fourier Transformation.

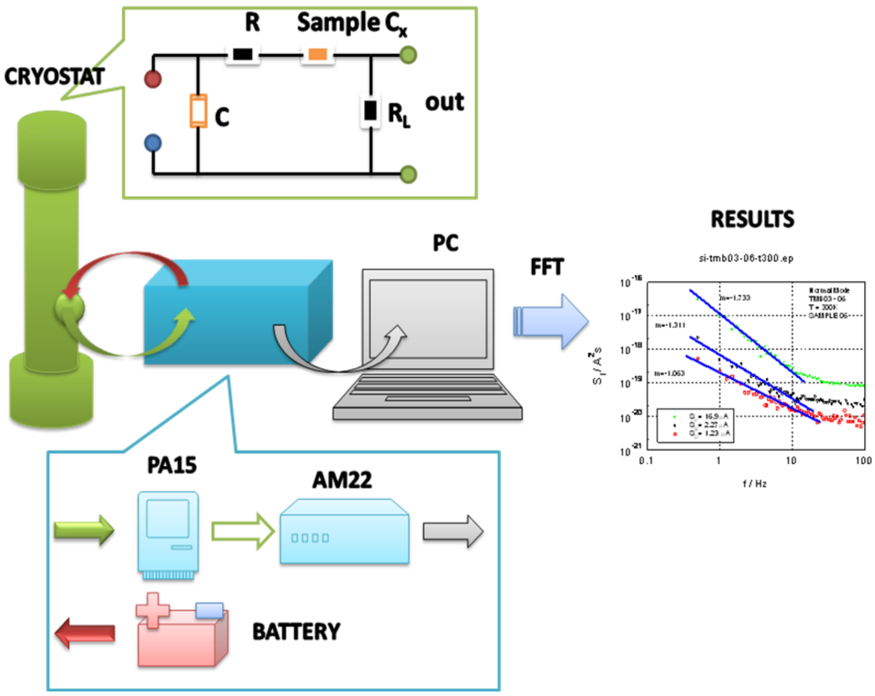

Fig. 1. Block diagram of noise measuring set-up with helium cryostat

Sample capacity is measured using RLC-meter Agilent E4980A.

2.2. EXPERIMENTAL RESULTS

The noise and C-V characteristics of the tantalum Ta capacitors with manganese dioxide cathode were analyzed in the temperature range 10 to 400 K. The dielectric layer was prepared by anodic oxidation and the thickness was 28 nm for sample TMB03-06. The sample TMB03-06 has nominal capacity $C = 100\mu F$ and rated voltage is 6.3V.

The low frequency noise was measured using load resistance R_L = 1 kΩ. From the measured noise voltage the voltage noise spectral density S_U was calculated. The current noise spectral density S_I was than calculated as:

$$S_i = \frac{S_u}{R_L{}^2}.\left(1+\omega^2.R_L{}^2.C_x{}^2\right) \qquad (1)$$

Where R_L is load resistance, C_x is the capacity of measured sample.

In order to evaluate the sample capacity we have measured C-V characteristics for different temperatures (see Fig. 2). We can see that the capacity decreases with decreasing temperature.

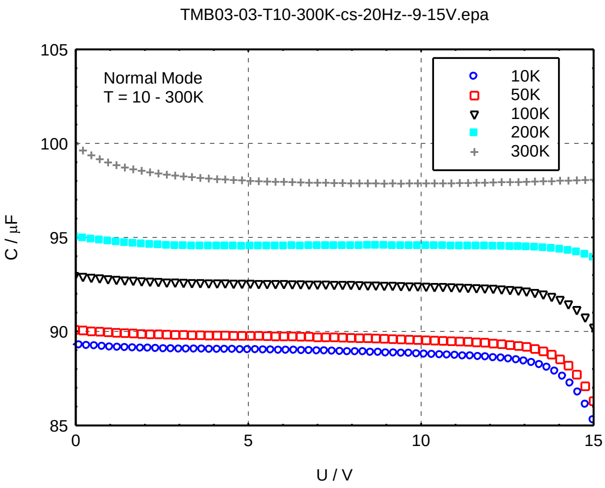

Fig. 2. Capacity vs. voltage characteristics of sample TMB03-06 for different temperatures: 300 K (top curve) down to 10K (lower curve)

Current noise spectral density frequency dependences are shown in Figs. 3 to 6 for sample TMB03-06 for temperatures 350 K, 200 K, and 10 K and for sample TMB03-15 for temperature 350 K. *1/f* noise is dominant for high currents for all temperatures, while GR noise, shot noise and thermal noise are observable for low current values mostly for temperatures higher than 200 K. GR noise was observed for the sample TMB03-06 for temperature 10 K and the current 1.16 µA, while for sample TMB03-15 and temperature 350 K GR noise is observed for current 8.6 µA (see Figs. 3 and 6).

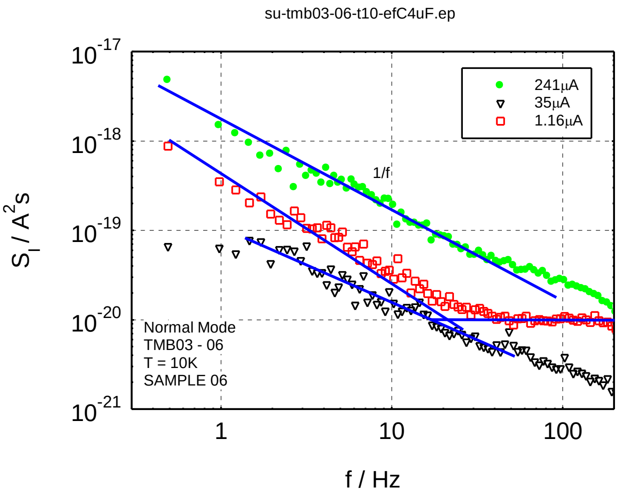

Fig. 3. Current noise spectral density vs. frequency of sample TMB03-06 for temperature T = 10K. GR noise detected for current I = 1.16 µA

We suppose that Poole-Frenkel charge carrier transport mechanism is a source of GR noise. Poole-Frenkel mechanism is dominant for the charge carrier transport in the low electric field bellow 1 MV/cm for the room temperature. With decreasing temperature this mechanism became negligible and it is pronounced only for very low currents, while for elevated temperature it became more important also for higher electric field. We can also see that 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. Charge a carrier tunneling is in the first approximation temperature independent and then it is dominant current mechanism for temperatures lower than 200 K. We suppose that the source of *1/f* noise is tunneling through the insulating layer at temperature lower than 200 K.

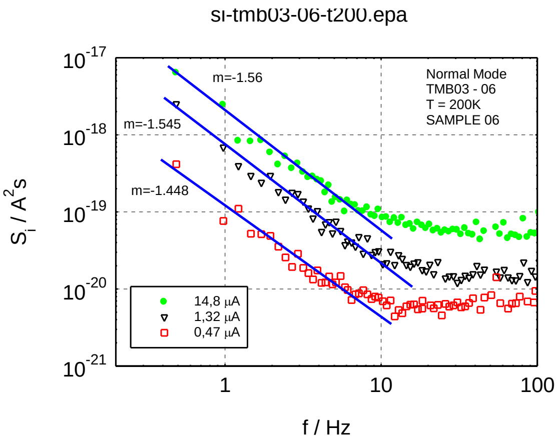

Fig. 4. Current noise spectral density vs. frequency of sample TMB03-06 for temperature T = 200K.

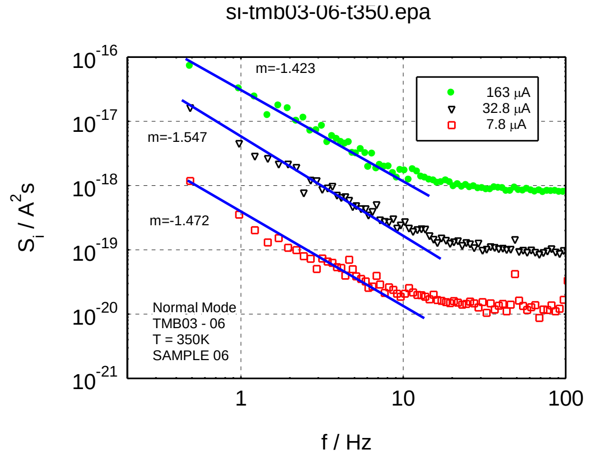

Fig. 5. Current noise spectral density vs. frequency of sample TMB03-06 for temperature T = 350K.

Current noise spectral density increases with the temperature and it is proportional to the I_n, where m is about 1.5 as is shown in Fig. 6.

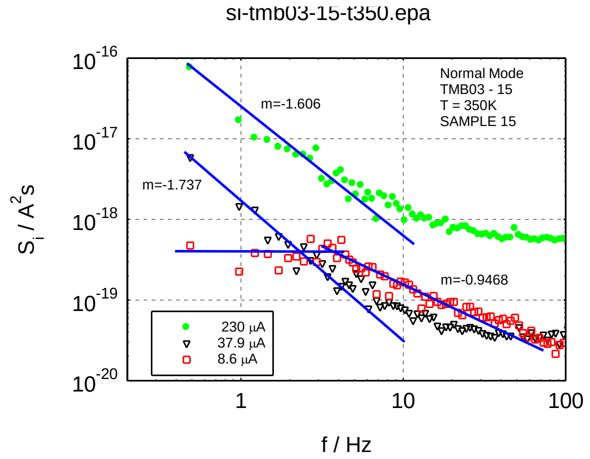

Fig. 6. Current noise spectral density vs. frequency of sample TMB03-15 for temperature T = 350K. GR noise detected for current I = 8.6 µA

This is probably due to that the noise spectral density has shot noise component or the low frequency noise is influenced by the fluctuation of the Schottky barrier height during the electric field application. There is external electric field given by the applied voltage and insulating layer thickness and internal electric field component dependent on the redistribution of electrical charges (ions and traps) in the insulating layer. Insulating layer contains high number for oxygen vacancies and defect sites of the order of 10^{18} to 10^{20} due to the oxide layer creation by anodic oxidation. Oxygen vacancies act as donor in the insulating layer and then the insulating layer can be treated as the n-type semiconductor. Total charges on donor sites depends on the applied and temperature.

3. CONCLUSION

Capacitors with Ta_2O_5 dielectric layers of thickness about 28 nm prepared by anodic oxidation were studied. The measuring set-up exploiting helium cryostat for the measurements in the temperature range from 10 K to 400 K was arranged.

C-V characteristics for different temperatures were measured for our samples. The capacity decreases with decreasing temperature. The capacity value was used for the calculation of the current noise spectral density from the measured values of voltage noise spectral density.

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.

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