LOW FREQUENCY NOISE OF TANTALUM CAPACITORS*

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A low frequency noise and charge carriers transport mechanism analysis was performed on tantalum capacitors in order to characterise their quality and reliability. The model of Ta-Ta₂O₅-MnO₂ MIS structure was used to give physical interpretation of VA characteristic both in normal and reverse modes. The self-healing process based on the high temperature MnO₂-Mn₂O₃ transformation was studied and its kinetic determined on the basis of noise spectral density changes. The correlation between leakage current and noise spectral density was evaluated and noise reliability indicator was suggested. In normal mode the noise spectral density at rated voltage increases with second power of current and it varies within two decades for given leakage current value. In reverse mode there is only weak correlation and for given applied voltage, the leakage current for all ensemble varies only by one order, whereas the noise spectral density of the same samples spread in five orders.

Keywords: Tantalum capacitors, Noise in Tantalum capacitors

INTRODUCTION

Charge carrier transport through amorphous layers is a main source of current fluctuations. They are result of stochastic processes as a charge carrier trapping, free charge carriers avalanche, thermal instabilities regenerative microbreaks, the isolation layer thickness variation etc. We concerned our studies on charge carrier transport and current noise spectral density to identify the sources of these fluctuations.

Noise spectral density in low frequency range may be considered as a superposition of $1/f^a$ noise, burst noise, shot noise and thermal noise. Fluctuation of polarisation and fluctuation of mechanical strain may cause another kind of noise, which may be of importance. Last is the contact resistance noise component, which also makes some structures be noisy. Two kinds of burst noise can be distinguished: Partial discharges in high electric field and regenerative microbreaks cause two state impulse like noise, whereas charge transport and polarisation fluctuation bring continuous noise spectrum. Irreversible processes, due to crystallisation of

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amorphous layer, oxide reduction and electric field inhomogenities, are responsible for thin insulating film structure degradation. It was found, that for the same value of DC component of leakage current identical samples have different value of dispersion or current noise spectral density. This feature was used as a quality and for some cases also as reliability indicator. For a good technology the current noise spectral density is proportional to the square of DC current component and then the ratio of this two quantities can be used as a quality indicator.

CHARGE CARRIER TRANSPORT

A large number of amorphous insulating films are known which, when a high electric field is applied, exhibit current flow, which increases roughly exponentially with applied voltage [1]. Amorphous Ta_2O_5 films are formed by the anodic process and for the second electrode MnO_2 is used. Such structure can be considered as MIS (metal-insulator-semiconductor) diode [2].

The mechanism which can explain VA characteristics of $\text{Ta-Ta}_2\text{O}_5\text{-MnO}_2$ structure depends on temperature and at low applied voltage and room temperature current is carried by thermally excited electrons hopping from one isolated state to the next. This mechanism yields an ohmic characteristic, exponentially dependent on temperature.

At high fields and room temperature the rate limiting step in the current flow is field-enhanced thermal excitation of trapped electrons into the conduction band. This process is known as Poole-Frenkel effect and it is also one of fluctuation source.

NOISE

Noise measurement was performed on special extra low noise amplifier [3, 4]. Measurements frequency range was from 10 mHz to 300 Hz. The noise spectral density is $1/f^a$ type in the low frequency range 10 mHz to 300 Hz. Sources of such fluctuations are traps with exponential distribution of relaxation times, fractal processes created by microbreaks, thermal instabilities and others. The second type of noise fluctuations is spectral density given by white or pink noise. In this case the noise spectral density is constant in low frequency range and for frequency higher than corner frequency it decreases as a f^{-2} .

FIGURE 1 Current noise spectral density dependence on leakage current. Measured for 1 sample at $f=10$ Hz.

FIGURE 2 Current noise spectral density dependence on leakage current. Measured for ensemble of samples.

Current Dependence of Noise Spectral Density

Noise spectral density is a quadratic function of the current, when the electric field strength in isolating layer is so low that avalanche process cannot occur (Fig. 1).

When the noise is generated on contacts, then current noise density is proportional to higher power of current and experimentally the values between the 4th to 6th power were observed. Figure 2 show such behaviour for large ensemble of Ta capacitors.

Frequency Dependence of Noise Spectral Density

There are two kinds of noise spectral densities – generally $1/f$ corresponding to fundamental noise sources and $1/f^a$ type noise corresponding to excess current. The second one is related to quality of these devices.

Measurement performed at very low frequency range 10 mHz to 1 Hz reveals, that for some samples noise is $1/f^a$ type, but we observed some time instability, which is probably

FIGURE 3 Time dependence of noise voltage before self-healing event.

FIGURE 4 Time dependence of noise voltage after self-healing event.

related to self-healing process. This process occurs in defect spots of dielectric layer, where a Joule heat is generated due to excess shunt current. The self-healing is based on the high temperature transformation:

The Mn_2O_3 form has several orders higher resistivity than MnO_2 and then the dielectric breakdown is interrupted and the sample quality improves. We observed that after self-healing event, the noise spectral density decreases, but in some cases the burst noise appears. Figures 3 and 4 show the change of noise voltage due to self-healing – the $1/f^a$ noise is changed into the superposition of the burst noise and $1/f^a$ noise with lower noise spectral density.

The noise spectral density is one of parameters describing quality of Ta capacitors for application in filters and low noise amplifiers. In Figure 5 the dependence of noise spectral

FIGURE 5 Noise spectral density vs. leakage current in normal mode.

FIGURE 6 Noise spectral density frequency dependence before (A) and after (B) ageing.

density on current is given for rated voltage in normal mode. The noise spectral density is $1/f^a$ like for all samples in both operating modes.

In normal mode the ensemble of 80 measured samples shows noise spectral density varying approximately two decades for given current and increasing with the second power of leakage current value (see Fig. 5). In reverse mode we didn't observe such dependence.

The excess noise is not stable and we believe, that it has strong correlation with self-healing effects. In Figure 6 a voltage noise spectral density frequency dependence is shown before (A) and after ageing (B), which caused a considerable decrease in a excess noise component. However, the prolonged exposure of the sample to a improperly high voltage (twice the rated voltage for several hours) have negative effect on capacitor structure and subsequently the noise spectral density increases.

NOISE EQUIVALENT CIRCUIT

Experimental results are used to propose equivalent circuit diagram for burst noise source, as is shown in Figure 7, where D denote MS diode. This metal–semiconductor diode is non-intentionally build up due to self-healing process in tantalum pentoxide thin layer defects and consist of Ta and Mn_2O_3 .

FIGURE 7 Equivalent circuit for burst noise source.

FIGURE 8 Noise spectral density frequency dependence measured on load resistance $R_L = 1 \text{ k}\Omega$ and $10 \text{ k}\Omega$

In Figure 7, C_X denote capacitance of measured sample and R_L is load resistance. Due to that contact resistance R_K is negligible, the absolute value of load impedance affect the frequency dependence of noise spectral density (see Fig. 8). Then current noise spectral density is given by:

$$S_I = \frac{S_U}{R_L^2} (1 + \omega^2 R_L^2 C^2) \quad (1)$$

where S_U is measurable quantity – voltage noise spectral density on the circuit output.

Current noise spectral density measured at the same DC current component for different value of load resistance shows that equivalent noise source has series resistance of the order of kilohms. In many cases of PN junction devices the series resistance is about $10 \text{ k}\Omega$.

NOISE RELIABILITY INDICATOR

Another result of our studies is that the current noise spectral density is related to the technology. It has been observed that capacitors with the same DC component of the leakage current show different noise spectral densities. Noise and leakage current constitute the reliability indicators for the capacitors.

In our investigation, the measurable quantity, which can be used for quality and reliability testing, is indicator M_Q given as

$$M_Q = \frac{S_I}{I^2} f \quad (2)$$

To get a good measurement resolution, it is necessary to carry out measurements in the region where the expected noise component magnitude is distinctly higher than that of the background noise. The range of operating points, where the noise measurements provide most distinct information about the excess noise, is confined to a relatively narrow frequency

band, 0.1 to 10 Hz. Measurement in mHz region requires total sampling time of the order of 1 hour, therefore the frequency range suitable for testing is about 10 Hz, with the total sampling time of about 10 s.

CONCLUSION

Charge carrier transport in thin isolating layer create excess noise, which is superposition of $1/f^a$ and G-R noise. It has been observed, that samples with the same DC current have different values of noise spectral density. We suppose, that DC current is a sum of at least two independent current flow mechanisms, which have not the same noise intensity.

The most important sources of fluctuation consist in regenerative microbreaks, fluctuation of polarisation and mechanical strain. The frequency dependence of noise spectral density in mHz region gives information on slow irreversible processes of tantalum pentoxide crystallisation and oxide reduction. The self-healing process can improve sample quality due to leakage current and noise reduction.

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