NOISE INVESTIGATIONS ON THICK FILM RESISTORS†

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Compared to metallic thin films or wires thick film resistors have a rather complex structure. Transition metal oxide particles are embedded into a glassy matrix. The resistivity depends heavily on the percentage of the constituents in the composition. It is believed that the main part of the resistance stems from the touching areas of conductive grains and that the conduction is by tunneling.

To give a better insight a noise spectrum analysis has been developed. A DC current is passed through the sample to be measured. The output noise voltage is analyzed between 1.6 Hz and 25 kHz using a commercial third-octave analyser.

Results are given of an experiment in which the glassy matrix of thick film resistors was etched away step by step and the noise was measured vs. the number of etching steps.

1. INTRODUCTION

Excess noise (often called "current noise") has been observed in all types of non-pure metallic resistors, including thick film resistors. The power spectrum of this noise may be expressed in the following general form:

$$S(f) = \text{const} \frac{I^\beta}{f^\alpha} \quad (1)$$

where I is the DC current flowing through the device, f frequency of measurement, $\beta \approx 2$ and $\alpha \approx 1$. The current dependence may be easily interpreted as the fluctuation of the conductance or resistance.³

The structure of a thick film resistor is very complex. Conducting metal oxide grains are embedded into a glassy matrix. While at low resistivities the grains probably touch each other and the resulting resistivity is determined by constriction resistances, at high resistivities the main factor is the doped glassy matrix. There is a strong belief² that the main conduction mechanism is the tunneling.

2. NOISE MEASUREMENTS

The noise measuring setup is shown in Figure 1. In series with the resistor R_m to be investigated there is an excess-noise-free (wiresound) resistor of 100 kilohm. The DC

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FIGURE 1 Noise measuring setup.

current flowing through R_m is provided by four standard batteries 4,5 V each. The total squared noise voltage across R_m is

$$u^2 = 4kT(R_s \parallel R_m)\Delta f + k^2 I^2 R_m^2 \frac{R_s^2}{(R_m + R_s)^2} \frac{\Delta f}{f} \quad (2)$$

where R_s is the series resistor, k a proportionality factor, I the DC current flowing through R_m . Since the latter is $I = U_{DC}/(R_s + R_m)$

$$u^2 = 4kT(R_s \parallel R_m)\Delta f + k^2 U_{DC}^2 \frac{R_m^2 R_s^2}{(R_m + R_s)^4} \frac{\Delta f}{f} \quad (3)$$

where the first term is the thermal noise and the second the excess one. It has a maximum when $R_m = R_s$; moreover the JFET preamplifier produces the least noise if $R_m \parallel R_s \approx 50 \text{ k}\Omega$. So this setup provides the best results with $R_m = 30 \dots 200 \text{ kilohms}$.

For the order of $3 \dots 30 \text{ kilohms}$ a bipolar transistor preamplifier is the proper selection.

The output of the preamplifier is connected to a main amplifier with a gain of 1000. Both units are battery operated and enclosed in steel boxes. The amplified noise signal was analyzed formerly by a home made active filter having 9 bands between 10 Hz and 10 kHz and was detected by a time varying integrator.³ Now, the latter units are replaced by a real-time spectrum analyser of type Brüel-Kjaer 2131 which works within 1, 6 Hz and 20 kHz providing 41 third-octave bands. A typical noise spectrum of a thick film resistor is shown in Figure 2.

FIGURE 2 Typical noise curves.

3. SAMPLE PREPARATION

Samples were made on 96% alumina substrate using a ternary conductor ink (PdPtAg, type REMEX 2014) and a ruthenium-oxide resistor ink of 100 kilohm per square (REMEX 8051). The samples were fired at 850°C for eight minutes while the total cycle continued for 65 minutes. As we will see later the repeated firing (refiring) is an important element of our investigations. All subsequent refirings were done under the above circumstances.

4. INVESTIGATIONS ON SAMPLES

The role of the glassy matrix has been investigated by partial etching. The samples were etched in a dilute water solution of 0,05% fluoric acid and 0,01% nitric acid for a period of 0...16 minutes and subsequently they were immediately rinsed by deionized water as well as methanol and finally they were dried in 100° air. The composition of the etchant and the time was set to obtain a well-observable dissolving effect but without making coarse damages on resistors.

Figure 3 shows the noise factor (in arbitrary units) vs. etching time. It is interesting that two valleys are superimposed on a monotonous curve.

The resistance of the samples increased in response to etching. This was almost linear with a slope of 2,4 per cent per minute. The increase can be explained by the fact that a part of the resistor body (the poor conducting glass) is removed.

FIGURE 3 Noise vs. etching time.

To stabilize the etched resistors we applied 1-3 refirings. The change in resistance - which is always negative - is shown in Figure 4. The loss of glass probably

FIGURE 4 Resistance change vs. etching time.

results in more directly touching ruthenium oxide grains. What is more interesting is that the maxima of Figure 4 coincide with minima of Figure 3. No explanation is available at present.

Similar resistance-etching time characters have been found on 1 and 10 kilohm per square resistors (8031 and 8041). On the other hand, refiring of unetched resistors resulted in always decreasing resistance.

While the experiments described above gave only initial results we hope that combining them with another microanalytical investigations (say electron microprobe) we will understand better the basic properties of thick film resistors.

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