phys. stat. sol. (a) 40, K185 (1977)

Subject classification: 14.3.3; 22.8.2

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Noise in Spinel Ceramics

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Introduction The current noise in bolometers with a negative temperature coefficient has been ascribed to poor electrical contacts /1, 2/. It is found also that a major portion of the noise can be attributed to the method of applying electrodes to the flakes /3, 4/. The results given here are from a study of the current noise produced in thermistor bolometers, constructed from mixtures containing iron and a mixed oxide, both belonging to the structural class known as "spinels", with a composition of $Mn_xCo_yNi_zO_4$ (where $x + y + z = 3$). Measurements were made with four and two electrical contacts for comparison. The purpose of the investigation was to examine the additional noise arising from the passage of direct current through the bolometers and to attempt to distinguish between external and internal noise sources.

Experimental methods To investigate the electrical noise an audio frequency spectrometer consisting of several low-noise, high-gain amplifiers, a band-pass filter (consisting of a modulator and a low-pass filter), a multiplier used as a squarer, an averaging filter, and a chart recorder was used. A block diagram of the measurement system is shown in Fig. 1.

The specimen and its bias circuit was kept in a well-shielded metal box connected to the pre-amplifier by means of shielded cables. Absolute calibration of the spectral noise density was performed with the help of the Johnson noise in a known resistor. Bias current was provided from a battery source through a series of metal-film re-

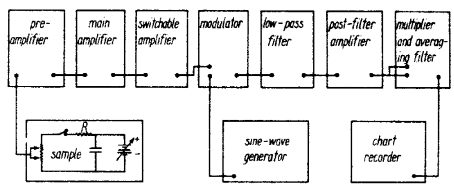

Fig. 1. Block diagram of voltage noise measuring system

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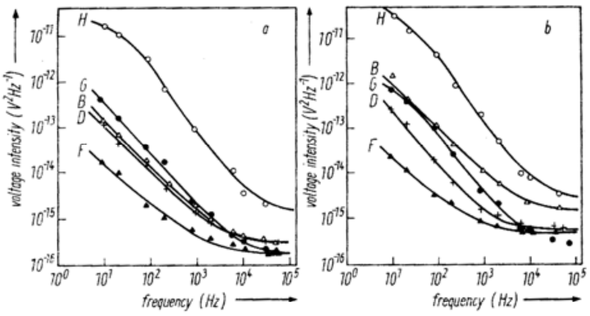

Fig. 2. Current-noise spectral intensity of flakes a) with four terminals, (B) △ I = 72.6 μA, β = 1.0, (D) + I = 113.9 μA, β = 1.0, (F)▲ I = 131.8 μA, β = 0.9, (G)● I = 116.6 μA, β = 1.1, (H) ○ I = 58.0 μA, β = 1.3; b) with two terminals, (B)△ I = 78.6 μA, β = 1.0, (D)+ I = 130.8 μA, β = 1.2, (F)▲ I = 133.2 μA, β = 0.9, (G)● I = 133.5 μA, β = 1.2, (H)○ I = 57.1 μA, β = 1.3

sistance (R) chosen to be about a factor of 10 greater than the flake resistance. The reference signal in the active band-pass filter was constant sine-wave with an amplitude in order of 20 V p-p in a range of frequencies from 2 Hz to 45 kHz. In making the noise measurement sufficient time was allowed for the system to attain equilibrium.

Results and discussion The results were obtained with the samples in Table 1. The frequency dependences are shown in Fig. 2a and b, where possible a fit has been made to the uncorrelated sum of current noise with $\overline{U_1^2} = a^2/f^\beta$ and Johnson noise with $\overline{U_2^2} = b^2$. Also the results show there is no significant difference between two and four terminals measurements at high frequency. The values of α, β in (1) were found to be 1.6 to 2.1, and 0.9 to 1.3, respectively:

$$\overline{U^2} = C_o \, I^\alpha / f^\beta . \tag{1}$$

There are several difficulties in trying to relate these results to physical mechanisms. There is, first of all, the lack of data on various important parameters such as carrier densities, mobilities, and lifetimes in these materials. Secondly, the conduction mechanism of the mixture of the transition metal oxides is not fully understood since air gaps are always present in sintered polycrystalline materials.

Table 1

Data about the samples

samples	composition			thickness	temp. coeff. of resistance	activation energy
	Mn_x	Co_y	Ni_z	(μm)		(eV)
B	1.5	1.5	-	145	4.4%	0.35
D	1.45	1 45	0.1	140	3.9%	0.34
F	1.35	1.35	0.3	170	4.1%	0.31
G	1.25	1.25	0.5	130	4.2%	0.33
H	1	1	1	155	4.5%	0.31

Even in well sintered materials the apparent density is always lower than the calculated value. However, comparing the current noise intensity obtained for two contacts with that obtained for four contacts, it appears that the noise possibly originates from bulk effects, rather than at the contacts.

The empirical equation of Hooge /5/ can be rearranged as follows:

$$S_{\Delta U}/U^2 = (1/N_{tot})(C/f) = Cq\mu R/L^2 f \quad , \tag{2}$$

where C is an experimental constant independent of temperature, μ is the mobility, q is the electron charge, U is the applied voltage, $S_{\Delta U}$ is the voltage noise intensity, f is the frequency, and R is the resistance between the contacts which are a distance L apart.

Experimental mobility data are not generally available and Volger /6/ suggests that conductivity and Hall effect measurements on granular semiconductors are impossible to analyse in terms of mobility and carrier density because of the presence of thin high resistivity intergranular spaces. To analyse the data the quantity C_o in (1) was calculated and by taking Hooge's value of $C = 2x10^{-3}$ in (2) the mobility values were obtained as in Table 2. We leave others to decide whether these are reasonable values and hence whether Hooge's formula applies.

Table 2

Experimentally determined values of mobility

sample	10^{-4} C_o four terminals	10^{-4} C_o two terminals	μ (10^{-2} cm/Vs) inner contact	μ (10^{-2} cm/Vs) outer contact
B	15.6 to 21.5	1.1 to 1.5	4.0 to 5.0	5.0
D	12.9 to 15.2	0.41 to 0.67	0.5 to 1.0	1.0 to 1.5
F	0.13 to 0.18	0.10 to 0.12	0.015 to 0.017	0.03 to 0.04
G	6.4 to 8.0	4.4 to 6.1	10.0 to 15.0	10.0 to 15.0
H	750.0 to 924.0	776.0 to 913.0	5.0 to 7.0	10.0 to 15.0

Comparing the current noise obtained for all of the samples, it appears that the current noise intensity decreases to a minimum value by adding nickel (sample F) and then starts to increase again.

For samples B, D, and F the noise spectra are fairly well described by a 1/f dependence.

For samples G and H at high current levels slight flattening of the spectra was observed at low frequency. This has also been observed in similar material by Van Vliet et al. /7/ who obtained comparable noise intensities. They discuss various possible causes of this effect. Our data does not provide more significant evidence on this point.

Suggestions have been made for various noise mechanisms. We have measured the activation energy and temperature coefficient of resistance and the data is given in Table 1. No significant correlation was found.

Acknowledgements

The authors wish to thank R.J. Mytton, R.K. Benton, and G. Casselton of the International Research and Development Co. Ltd., (IRD-Newcastle-Upon-Tyne) for fabricating the samples and many useful discussions.

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(Received March 3, 1977)