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ACCURACY OF MEASUREMENTS OF DYNAMIC CONDUCTANCE IN THE NORMAL STATE TUNNELING SPECTROSCOPY OF METAL OXIDES

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An application of harmonic modulation technique for the measurement of dynamic conductance of S-I-N and N-I-N metal oxide tunneling junctions has been discussed. The quantitative analysis of error components taking into account the influence of higher harmonics(approximation error) has been performed. We show that one can obtain the experimental data with relative resolution good enough for the subsequent numerical processing even at a presence of a steeply rising background in the tunneling conductance.

The normal state tunneling spectroscopy of metal oxide superconductive compounds shows promise for revealing the effects of electron-phonon interaction in these materials. The matter is that the short coherence length typical for the high-T_c superconductors being comparable to the thickness of the deteriorated surface layer limits the abilities of the superconductive tunneling spectroscopy. At the same time the surface layer of a superconductive metal oxide although being in normal state due to the oxygen deficit does not differ considerably in composition and structure from the superconductive compound. The self-energy effects appear as the pecularities in the odd part of the dynamic conductance of normal state tunneling junction. The spectral function of electron-phonon interaction can be thus reconstructed from the normal state tunneling data [1,2].

The normal state metal oxide tunneling junctions demonstrate a steeply rising with bias voltage $dI/dV(V)$ curve while the self- energy features to be detected are of low relative amplitude. The resistance of junction could vary within several orders of magnitude, say $0.1\Omega ... 100K\Omega$, and the granular structure of the metal oxide may cause an additional noise of $1/f$ type. Transport current flowing through the granular metal oxide structure could be of considerable amplitude. The rising background which could be either linear or parabolic makes impractical the use of bridge circuits

[3,4] to expand the low-level structures. Therefore the measuring circuit with extended dynamic range like one described in [5] is needed.

An additional error appears due to the finite amplitude of harmonic modulation (approximation error) because this latter should be high enough to provide the signal/noise ratio of 10^4 or more. However, at any finite amplitude of harmonic modulation the dI/dV depends not only on the first harmonic of the junction current but is a linear function of all the other existing odd harmonics of higher numbers as well. There is a similar situation with a second derivative, d^2I/dV^2. Considering these abandoned higher harmonics as an approximation error one can determine the actual accuracy of measurement. Practically only the nearest significant harmonic, the third one in case of the is necessary to take into account. The amplitudes of the higher harmonics could be calculated from the corresponding derivatives of tunneling current. These higher derivatives could be taken numerically after recording the $dI/dV(V)$ curve and the value of approximation error could be calculated for any given modulation amplitude. This way one can determine the optimal modulation amplitude to obtain the highest possible accuracy for the conductance curve of each tunneling junction.

The corresponding expressions are:

$$\frac{dI}{dV} = \frac{1!}{\delta V}(I_1 - 3I_3),$$

$$\frac{d^2I}{dV^2} = \frac{2!}{\delta V^2}(I_2 - 4I_4),$$

where I_n is a measured amplitude of n^{th} harmonic of modulation frequency in the junction current.

From another side:

$$3I_3 = \frac{\delta V^3}{8}\frac{d^3I}{dV^3},$$

$$4I_4 = \frac{\delta V^4}{48}\frac{d^4I}{dV^4},$$

and, respectively, the total error values, including the contributions of noise and higher harmonics for the first and second derivatives are;

$$\rho_1 = \sqrt{\left(I_1^2 + 9I_3^2\right)/I_r^2},$$

$$\rho_1 = \sqrt{\left(I_2^2 + 16I_4^2\right)/I_r^2}$$

where $I_r = V_r \cdot dI/dV$ is the random noise component of junction current caused by the noise voltage V_r, measured at the potential terminals of junction. The resulting error values , ρ_1 and ρ_2 depend on both the modulation voltage and the degree of nonlinearity of the $I(V)$ and allow one to determine the suitable value for δV for each particular case. Fig.1 shows the results of a calculation of the total error of dI/dV for the numerical simulation of S-I-N junction at the energy gap region. The amplitudes of the first and third harmonics were calculated in the bias region of 10...150 mV and modulation amplitudes Of 0.1...1.5mV. The average values of error over the whole bias region were expressed as a function of modulation amplitude. These computations were performed for the three values of noise voltage(5,10 and 20 nV). It is obvious that even for the worst case (V_n = 20 nV) a relative error of 10^{-4} is achievable for the modulation amplitudes of 0.2...0.8 mV.

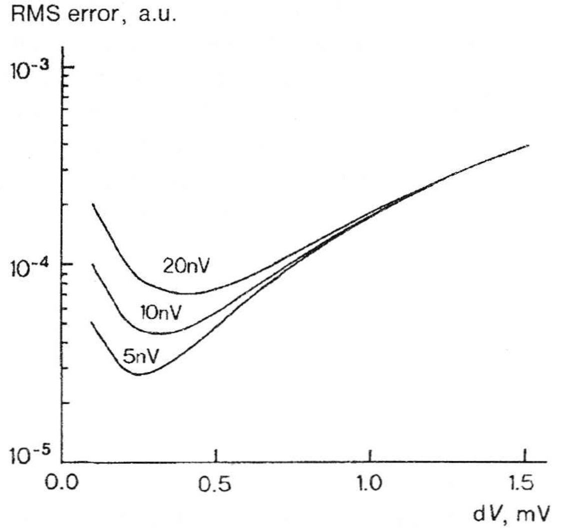

Fig. 1. Calculated total error for the simulated d*I*/d*V* measurement of S-I-N junction for three different noise values

An independent problem is how to choose the proper modulation amplitude to obtain the d*I*/d*V* data with a predicted accuracy, suitable for the further numerical processing. To determine the value of approximation error one can calculate the amplitude of third harmonic as a function of bias voltage using the third derivative taken numerically from the measured data (if necessary, the additional numerical filtering may be applied to reduce an excess noise). The application of such an approach is demonstrated in Fig.2. Here the amplitude of third harmonic derived from the experimental d*I*/d*V*(*V*) curve. is shown as a function of bias voltage for the two modulation amplitudes, 0.3 mV and 0.9mV together with the curves representing the total error including 20 nV of noise, a value typical for these measurements due to the excess 1/*f*-type noise generated by the ceramic, measured with the lock- in time constant of 1s. The modulation of 0.3 mV is obviously more suitable because it provides an error of $8 \cdot 10^{-5}$ determined almost by the random noise and the further improvement could be achieved by means of the numerical filtering. In the case of 0.9 mV modulation the approximation error is at least one order of magnitude larger than noise, reaching the level of $2 \cdot 10^{-4}$ in the region of energy gap and the loss of resolution is inevitable.

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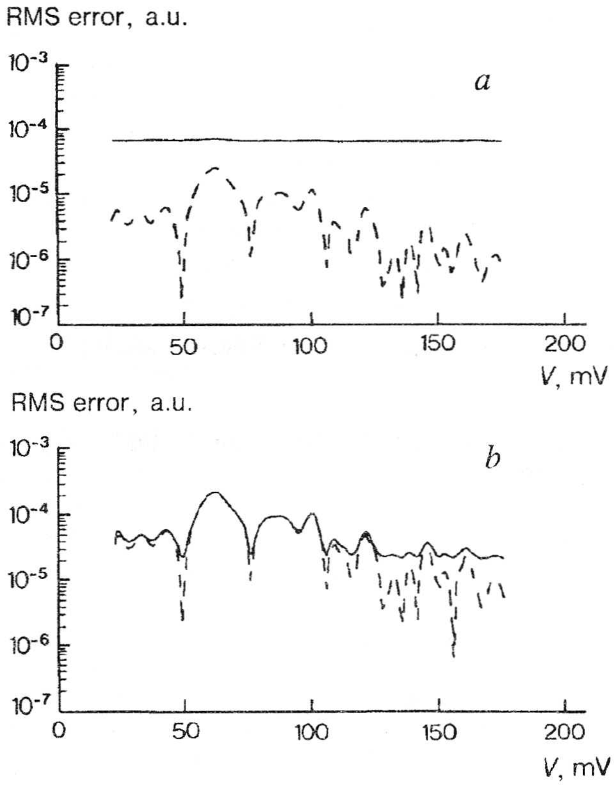

Fig. 2. Calculated third harmonic (dashed line) and total error (solid line) for modulation amplitude of 0.3 mV (*a*) and 0.9mV (*b*)

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