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HIGH-RESOLUTION MEASUREMENTS OF DYNAMIC CONDUCTANCE ON HTSC-BASED TUNNEL JUNCTIONS

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The AC modulation technique is the most common approach to measurement of low nonlinearities in the current-voltage characteristics of superconducting tunnel junctions. The highest resolution and accuracy are easy to obtain in the constant current mode of measurements ($dV/dI(V)$ and $d^2V/dI^2(V)$) employing a resistance bridge circuit [1,2]. The dynamic conductance data ($dI/dV(V)$ and $d^2I/dV^2(V)$) are more fundamental because the first derivative determines a density of states and the second one emphasizes the fine structure of the phonon spectra. phonon spectra. In this case the dynamic resistance data must be converted into dI/dV or d^2I/dV^2 form before further processing. Such a conversion may complicate the interpretation of data and, in some cases($|V| < \Delta_1 + \Delta_2$), produce a sufficient error. For such purposes the direct measurement of dynamic conductivity is preferable.

Instead of dynamic resistance, the active servo-control circuit is required to provide the constant voltage mode in measurements of the dynamic conductance. The amplitude of AC modulation must be stabilized with the great accuracy over the wide range of sample resistance. For detecting extremely low non-linearities (10^{-4} or less) the background component in the signal must be compensated, i.e., a kind of bridge network is required. The presence of an amplifier inside this network may complicate its stability due to variations of gain, input and output impedances and additional noise [3].

Here we describe a system for the precision measurements of dynamic conductance in which a special-designed AC conductance bridge provides true four-probe measurements of $dI/V(V)$ and $d^2I/dV^2(V)$ curves with relative resolution in dynamic conductance of about 10^{-6}. The range of sample impedance is extended down to less than 0.1 Ohm.

The circuit diagram of system is shown in Fig. 1. An AC voltage from output of the precision LF oscillator is applied to the bridge circuit via the decoupling transformer with two equal secondaries. The leakage capacities between the windings of this transformer are less than $2pF$ what is important to maintain the stability of the whole circuit. These two secondaries are followed by the equal resistive dividers with dividing ratio about 100. The output AC voltage of the first divider is reproduced on the potential probes of a junction by means of the operational amplifier arranged as a four-probe voltage follower. This op — amp drives the junction via a high-current buffer to provide required output current(> 1 Amp) and also controls the DC bias. The first arm of the bridge is formed by the junction R_s and the reference resistance box R_r connected in series. The second resistive divider provides a compensation AC voltage V_c to be subtracted from that dropped across R_r and serves as the second arm of the bridge.

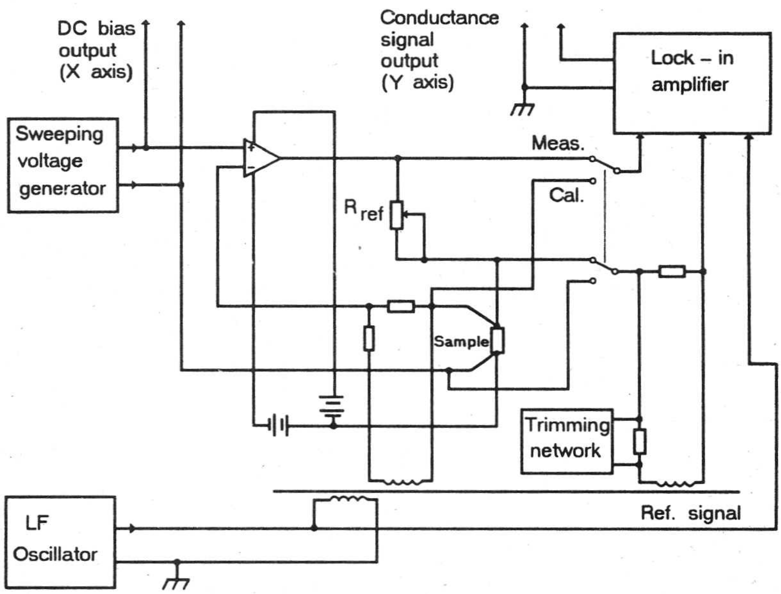

Fig. 1. A circuit diagram of conductance measuring system

The unbalance signal is amplified by a low-noise preamplifier and the rectified by means of the lock-in amplifier to obtain a final DC signal proportional to dI/dV or d^2I/dV^2 whether the lock-in is switched to "f " or "$2f$ " mode. The op — amp incorporated in the bridge circuit produces certain trouble. Because the open-loop gain of the op — amp is finite (typically < 1000 above 1 kHz), the closed-loop gain of the voltage follower is slightly lower than the unity. This introduces certain variations of V_s depending on the load impedance and can produce a bridge unbalance error. To eliminate this error there is a special arrangement including a two-position switch SW that connects the input of the low-noise preamp together with the second divider to the resistance box (a "measurement" position) or to the potential probes of a junction (a "calibration" position). In the second case it is possible to trim the amplitude and phase of the compensation voltage to be equal to that of modulation voltage. For such calibration the trimming network is incorporated in the second divider. In the "calibration" position it is also possible to tune a proper phase of the reference voltage for the lock-in amplifier. If the phase is tuned to maximum output in this position, i.e. while measuring directly the AC modulation voltage from potential probes, the output of the lock-in amplifier during an actual measurement may depend only on variations in the real part of the junction's complex conductance. As shown in Fig. 1, the total AC current I_{ac} flowing through the junction and the resistance box is

$$I_{ac} = V_s (G_s + i\omega C_s), \quad (1)$$

where V_s is the AC modulation voltage applied to the sample, G_s and C_s are the conductance and capacity of the sample, respectively. The real part of this complex current depends only on G_s and if the reference signal for lock-in amp is tuned in

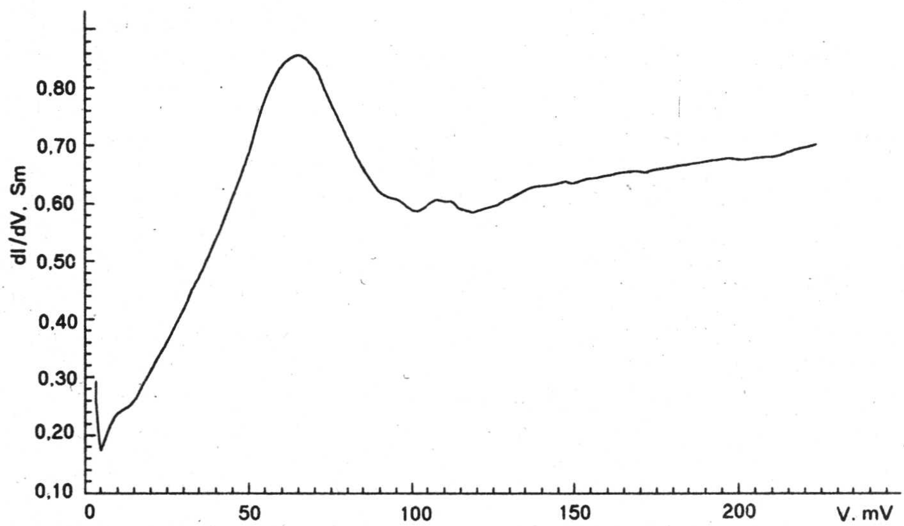

Fig. 2. The dynamic conductance curve (positive side) measured on Bi–Bi ceramic break junction

phase with V_s, the variations in sample capacity do not affect the resulting dI/dV data. The deviation of junction conductance ΔG_s can be expressed as

$$\Delta G_s = \mathrm{Re}(V_r - V_c)/R_r V_s .$$

A suitable range of modulation frequency for this system is 200–5000 Hz, the lower limit is determined to be sufficiently far from the mains frequency, the upper one deals with decrease in accuracy of the op — amp. For the best performance this frequency must be chosen far from nearest harmonics of mains frequency. The scanning DC bias is applied to the input of voltage follower from the sweeping voltage generator powered by a well-decoupled regulated power supply. Because the op — amp reproduces this voltage on potential probes with the great accuracy and extremely low offset (less than 1 μV), the DVM's input may be removed from the sample and connected to the source of bias voltage that simply avoids the influence of DVM's input impedance and possible noise current through the sample. The output data are recorded simultaneously by a $X-Y$ recorder and a digital data acquisition system consisting of two 6.5 — digit DVMs and IBM PC AT coupled via the IEEE — 488 bus.

Fig. 2 demonstrates a $dI/dV(V)$ curve of a break junction made of Bi-based HTSC ceramics (2223 phase). To emphasize the resolution of a system, the magnified part of this curve is shown in Fig. 3. It must be noted that the visible structure

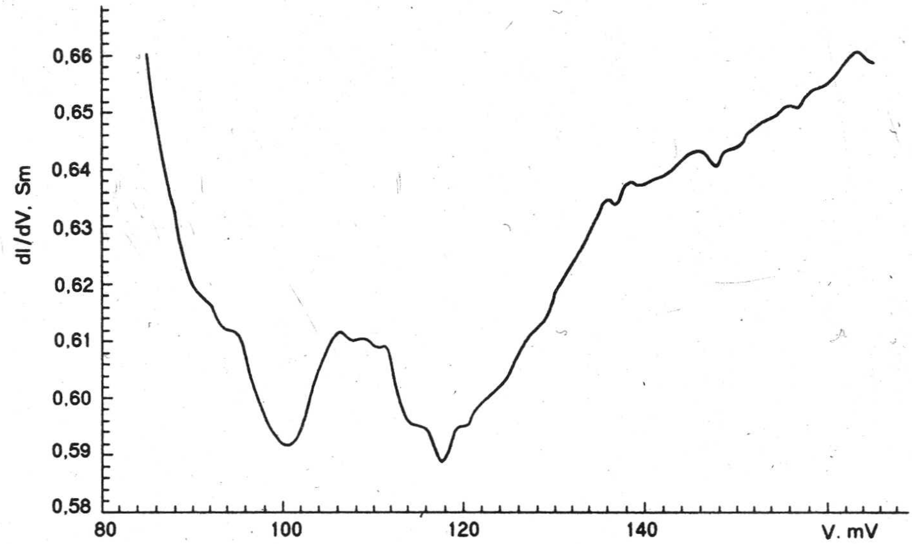

Fig. 3. A magnified part of dynamic conductance curves shown in Fig. 2

is well defined and present in large array of curves measured on the same sample. The presented one was taken at $T = 4.2$ K, AC modulation $V_{ac} = 80\,\mu$V RMS and lock-in time constant $\tau = 1$ s.

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