Purpose of the visit

Experimental study of high frequency Josephson dynamics and noise in planar YBaCuO/SrCaCuO/Au/Nb heterojunctions

Description of the work carried out during the visit

Unconventional properties of superconducting hybrid junctions with an interlayer comprising magnetic materials are of great interest for fundamental physical and electronic applications. L. Gorkov and V. Kresin predicted [1] an anomalously strong magnetic field dependence of superconducting critical current in Josephson junction with an artificial multilayer antiferromagnetic (AF) barrier, offering an opportunity for manipulation by weak external magnetic field. However, in S-AF-S (Nb-FeMn-Nb) junctions [2] with polycrystalline AF interlayer anomalous magnetic field dependence of the superconducting critical current was not observed. The giant proximity effect: an anomalously large value of the superconducting critical current has been found in the cuprate structures with thick AF oxide interlayers [3,4], but a question also exists whether the micro-shorts [5] may explain these observations. Recently group from IRE RAS has reported [6] on studies of $Nb/Au/Ca_{1-x}Sr_xCuO_2/YBa_2Cu_3O_{7-\delta}$ heterostructures with antiferromagnetic interlayer ($Ca_{1-x}Sr_xCuO_2$). Epitaxial thin films of $YBa_2Cu_3O_{7-\delta}$ and $Ca_{1-x}Sr_xCuO_2$ were grown by laser ablation on $NdGaO_3$ substrates. $Ca_{1-x}Sr_xCuO_2$ (x=0.15 or 0.5) films were 20 and 50 nm thick. Experimental results [6] show that the superconducting current is increased in the $Nb/Au/Ca_{1-x}Sr_xCuO_2/YBa_2Cu_3O_{7-\delta}$ heterostructures in comparison with $Nb/Au/YBa_2Cu_3O_{7-\delta}$ heterostructures [7] without AF layer. It was found also that the critical current in new structures is very sensitive to external magnetic field and its direction. At the same time heterojunctions driven far from equilibrium at microwave frequencies may demonstrate noticeable deviations of high frequency dynamical characteristics predicted by RSJ-model. Particularly, unusual and frequency dependent waveform of the critical current I_C, integer I_1, I_2 and non-integer $I_{1/2}$ Shapiro step amplitudes vs applied microwave field have been registered in $Nb/Au/YBa_2Cu_3O_{7-\delta}$ junctions [7]. In these connection studies of high frequency dynamics in new structures become important. Additional information on electron transport properties could be extracted also from linewidths of the Josephson self-oscillation and from spectral densities of current noise, emitted by heterojunctions at finite biasing voltages.

Description of the main results obtained

The spectral density of high frequency noise emission was studied using low noise cooled amplifier, directly coupled with investigated heterojunctions. The cooled amplifier has noise temperature T_N=8K, gain G=20.5 dB and the operating frequency band 0.9 – 2.1 GHz. The output signal was controlled by spectrum analyser, using room-temperature low noise preamplifier with G=40 dB and T_N=130 K, terminated by a detector, operating in quadratic (low signal) mode. All measurements were carried out in the microwave-screened room, using low noise analogous electronics, equipped (when possible) with battery power supply. Ambient temperature was T=4.2 K. Microwave mm-wave power was delivered from millimeter wave Gunn-Oscillators. The power and frequency of applied signal have been precisely controlled during the measurements.

By means of measurements of I-V curves under the influence of microwave power P_e at mm wave frequencies the usual integer Shapiro steps have been registered for the all samples under the test. The heterojunctions with the thickness of AF layer d=50 nm, x=0.5 and dimensions 10x10 μm (sample 274e) and 20x20 μm (274d) have been characterized. The case of x=0.15 has been studied only for the sample 269e with 10x10 μm for its relatively low impedance and weak coupling with HEMT amplifier. Note, the half-integer Shapiro steps n=1/2, 3/2, 5/2 have been registered at f=70 GHz for the both samples with area 10x10 μm. Fig.1. demonstrates the $I_C(H)$ dependences for two different samples on chip 274. It is seen that a very well repeatable split on the central peak of $I_C(H)$ is observed for the sample N274d. This issue we plan to investigate for junctions with the larger areas. Fig.2 show typical results of noise measurements observed for well matched high-impedance heterostructures. Our estimations of amplitudes of spectral density of noise power S_P tell us that no low-voltage nonequilibrium excess noise take place in these heterojunctions, demonstrating usual shot noise at large voltages V> 5 mV.

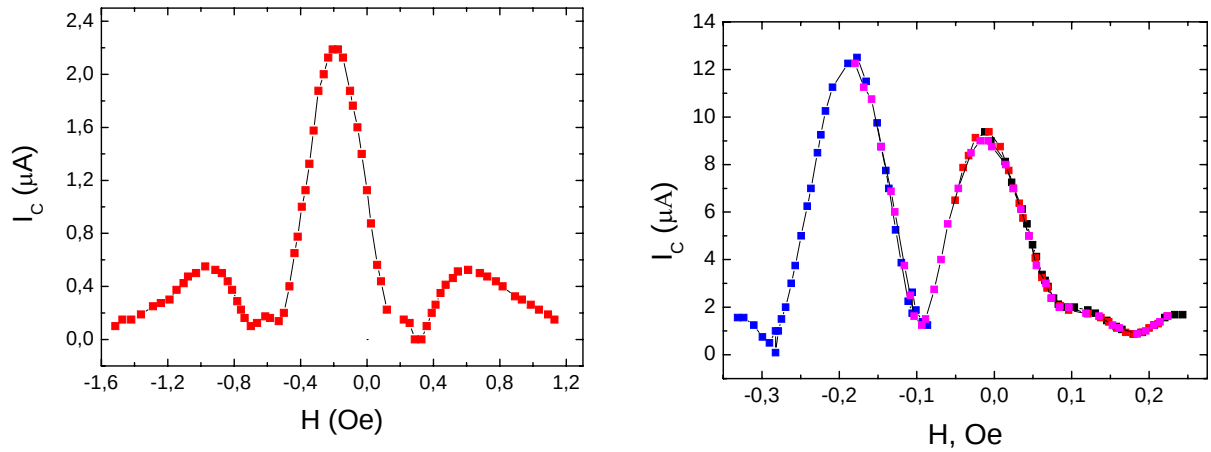

Fig.1. Magnetic field dependences of critical current I_C for $Nb/Au/Ca_{1-x}Sr_xCuO_2/YBa_2Cu_3O_{7-\delta}$ heterostructures with x=0.5: (a) junction area 10x10 μm^2 and (b) 20x20 μm^2. Plots are given without correction for residual magnetic field.

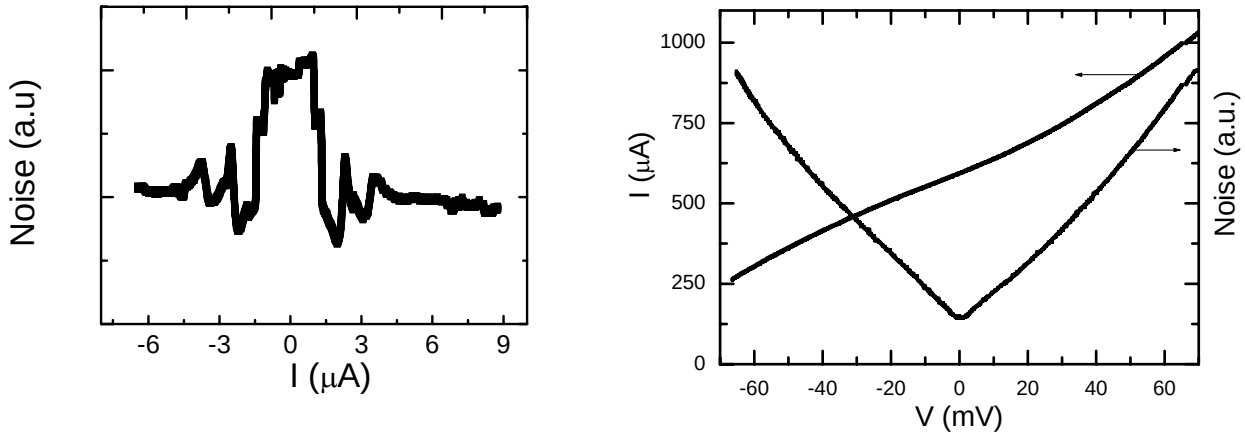

Fig. 2. Spectral density of noise power S_P for heterojunction N274e with normal state resistance R_N =110 Ω (a) the S_P is expanded by the Y-axis, current biasing corresponds to the voltages V<<1 mV, (b) S_P and I-V curve at V>1 mV.

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- Future collaboration with host institution

Long lasting collaboration between groups from DTU FYS and IREE RAS was already established many years ago. That significantly helps to minimize terms of technical and administrative preparations for specific measurements, planned for this project. In this connection we look optimistic for our future collaboration in the field of studies of novel interesting Josephson structures which will be designed and fabricated in IREE RAS and experimentally investigated at DTU FYS.

- Projected publications/articles resulting or to result from your grant

New results along with the data, obtained in IREE RAS just before visiting DTU, are currently analysed and discussed for preparation of a journal paper, as well for presentation to relevant international conferences/workshops.