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MM wave Josephson radiation in High-Tc bicrystal junction arrays

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ABSTRACT: High-T_c Josephson junction arrays with coupling by superconducting short-circuited (5 μm wide and 0.1 μm thick) coupled microstrip lines, provided dc bias in parallel, were fabricated on bicrystal sapphire substrates for experimental investigation of the phase-locking phenomenon. Josephson self radiation, emitted by the array was measured by an external 90 GHz receiver for different applied dc magnetic fields. The numerical simulation of array shows that strong interaction between Josephson junctions and the standing waves within structure require small enough damping $\alpha \leq 10^{-3}$ per coupling section for reduction of Josephson oscillation linewidth.

1. INTRODUCTION

The advantage of lock-in Josephson junction (JJ) arrays, consisted of lumped JJs, over a single JJ for applications in mm and submm wave oscillators and in low-noise front-ends of receivers are known (Han, et al 1994). Aiming at applications at frequencies laying above the energy gap of conventional superconductors, the high-T_C superconducting (HTS) JJs should have small enough spread of parameters. For present the minimal spread of 10-15% demonstrate HTS JJs on bicrystal $SrTiO_3$ substrates. $SrTiO_3$ has too large dielectric constant and thus is hardly applicable at submm waves. In this paper we report on fabrication, experimental and theoretical study of single layer JJ-arrays, based on YBaCuO thin film bicrystal JJs, deposited on promising for high frequency applications sapphire substrates. For lock-in operation all of JJs in array must oscillate at one desired frequency and have to deliver in-phase the emitted power to the common load. The first condition is reached by parallel voltage biasing, while the second one has been realized the JJ coupling by superconducting short-circuited coupled microstrip lines. Digital simulation of such circuit was carried out by PSCAN program (Kornev, et al 1997). The appropriate experimental multijunction Josephson structures were fabricated and measured by means of direct detection of emitted self-radiation. The obraned data are discussed and compared to digital simulations

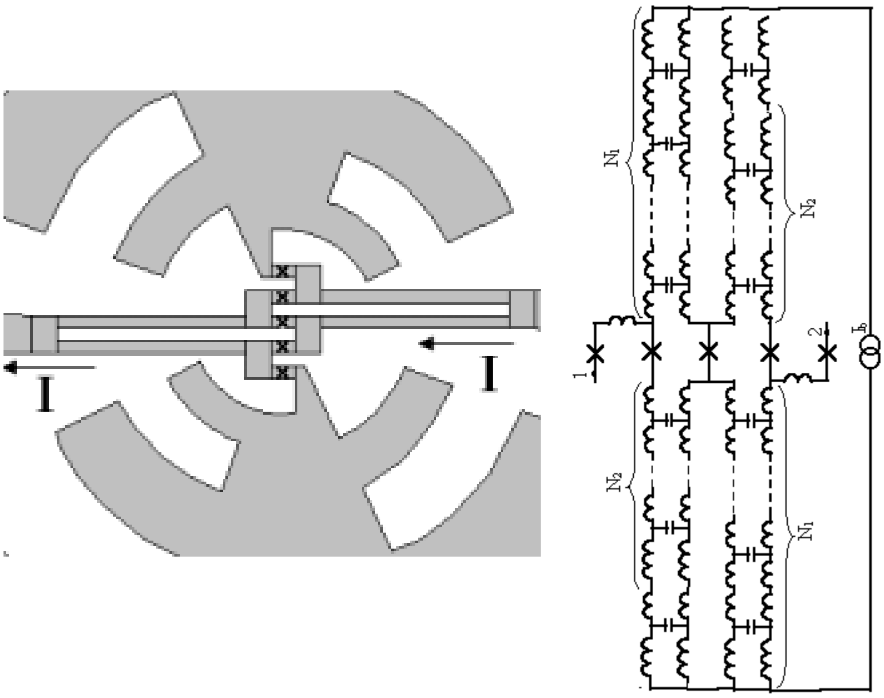


Fig.1. The layout and it's circuit model of the studied JJ array. Loop is 90 μm, strip width is 5μm. JJs are marked by crosses.

2. EXPERIMENTAL

The design and topology of 5-junction array, fabricated using YBCO thin film deposition over sapphire bicrystal substrate is shown on Fig.1. The short-circuited superconducting (5 μm wide and 0.1 μm thick) coupled microstrip lines of dc bias in parallel were designed to provide mutual interaction of JJs in array. Josephson self radiation, emitted by the array was measured by an external 90 GHz receiver at different fixed levels of applied dc magnetic fields. The fabrication techique for array is analogous to that for single YBCO thin film JJs on sapphire bicrystal substrate (Mashtakov 1999). Fig.2 demonstrate a typical exeperimental dependence P(V) of emitted power from 3-junction array vs bias voltage. No any significant difference from the P(V), corrresponding to emission from single JJ was revealed

The behaviour of emission characteristics of array demonstrates very strong dependence from H. Within one modulation period by H (due to SQUID loops in array) the value of P changed up to 10 times and the Δf - up to 3 times (see Fig.3). These loops made emission process less stable, moreover, spontanious flux pinning could destroy emission mode dramatically. However, an average broadenning of linewidth for array was no larger than that of single junction, with some narrow intervals by H of essential Δf rise by additional 3-4 times. For single junction, varying the applied magnetic field H, the value of differential resistance $R_d(V)$ at bias voltage V was changed which gave monotonous change of power P and the oscillation linewidth Δf. Increasing the H, the P(V) dependense could be plotted with well accuracy and the estimated linewidth was of a order larger, than predicted by RSJ model. $\Delta f= 41TR_d^2/R_N$ MHz for T=10K and R_N=2.45 Ω.

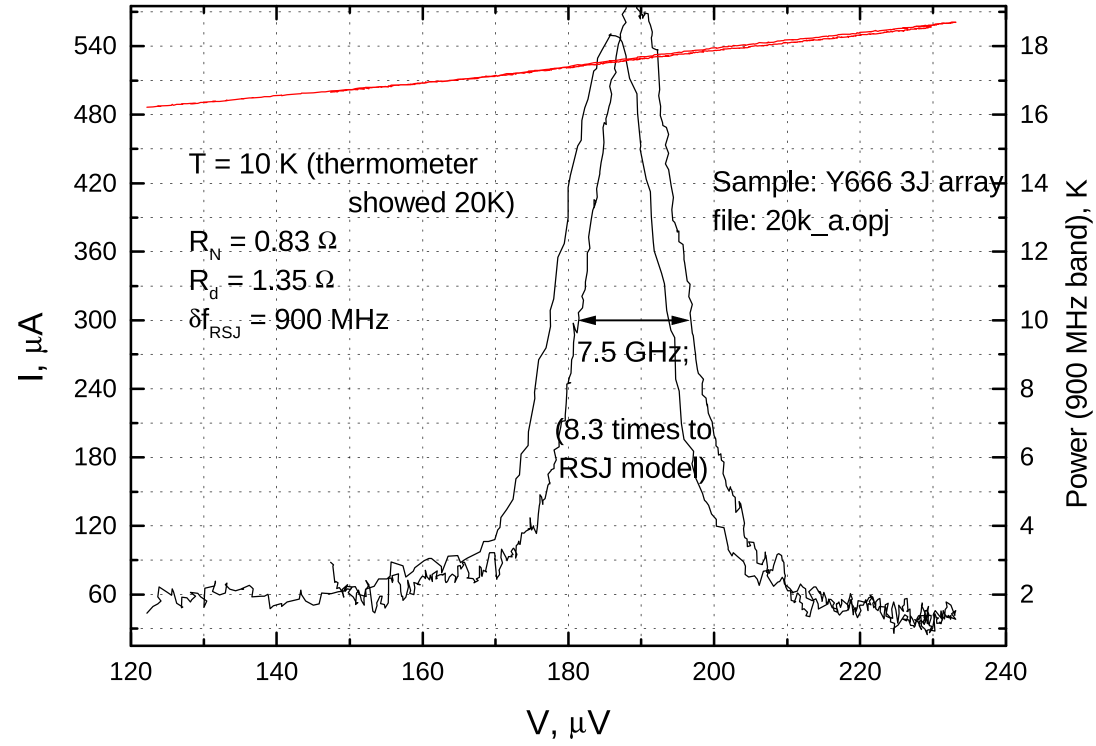


Fig. 2. Self-radiation power, emitted by 3-junction array, directly measured at 90 GHz

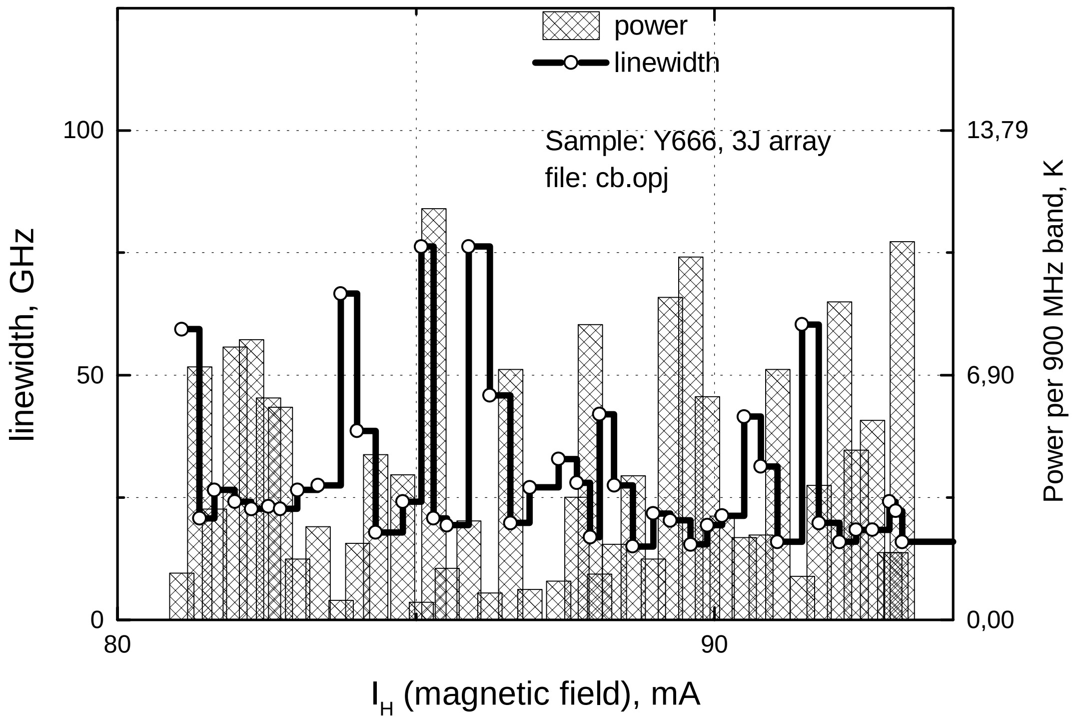
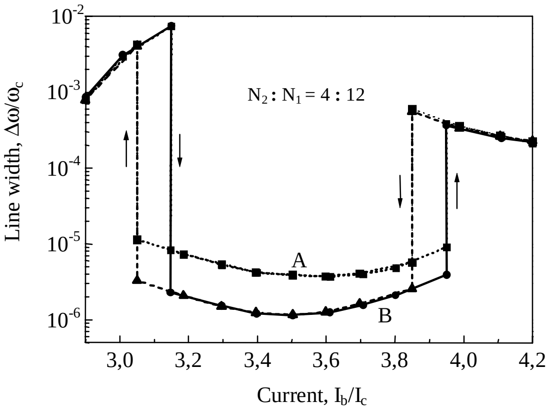


Fig. 3. Magnetic field dependencies for radiation power and linewidth for 3-junction array.



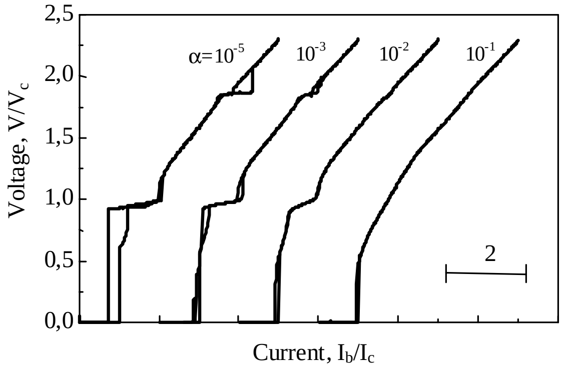


Fig.4. A set of I-V curves for Josephson junctions of the system at different values of high frequency loss coefficient α. McCumber parameter - β=1, ρ/R_n=10.

Fig.5 Oscillation linewidth dependence on bias current within resonance peak on I-V curve for the array at β=1, ρ/R_n=10, and $\alpha=10^{-3}$. A – for Josephson junction oscillations, B – for output signal V_{out}.

3. DIGITAL SIMULATION

We have performed numerical simulation of the experimentally studied system shown in Fig. 1. The long rectangular coupling loops between Josephson junctions in the real system imply shorted sections of a coupled microstrip line and hence can be modeled by the shorted sections of an equivalent two-conductor line, which in its turn, be modeled by the multi-element lumped LC-chain (Fig.1). This allowed us to perform digital simulation of the system by means of well known PSCAN program for the lumped Josephson junction circuits. According to the topology of the system shown in Fig.1 its equivalent scheme consists of identical LC-chains of number N_1 and N_2. An additional set of resistors connected to the capacitors are used for symmetric biasing. Fig. 4 shows a set of I-V curves for the JJ array with distributed coupling circuits at different values of the loss factor α. If α is 10^{-2} and less, one can see well pronounced resonance peculiarities on the curves that correspond to the standing wave excitation in the distributed coupling circuits. In this case the standing wave impact on JJ oscillation provide reasonable reduction in the oscillation linewidth. The linewidth reduction at loss factor $\alpha = 10^{-3}$ is presented in Fig.5. It should be emphasized that the standing waves in the distributed circuits are phase-locked just in-phase by their coupling via JJs. Therefore the amplitude of the output signal, applied to the antenna vibrators is about the sum of the amplitudes of the standing wave oscillations in the position where JJs are connected into the coupling lines. As it was found the optimal position providing maximum output signal corresponds to the ratio $N1/N2 \approx 0.25\ldots0.4$. It can be easily explained if we take into account that the standing wave excitation is provided by Josephson junction interaction with the wave of the current, and the output signal is formed by the standing wave of the voltage.

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