A SUPERCONDUCTING SINGLE FILM DEVICE OSCILLATOR MADE OF HIGH Tc AND LOW Tc MATERIALS

J. S. Martens*, J. B. Beyer, J. E. Nordman, and
G. K. G. Hohenwarter**
University of Wisconsin-Madison
Department of Electrical and Computer Engineering
Madison, WI 53706-1691

D. S. Ginley
Sandia National Laboratories, Organization 1144,
Albuquerque, NM 87185

ABSTRACT

We have constructed a superconducting oscillator made with single film devices. Circuits made of the high T_c superconductor TlCaBaCuO as well as those made with the low T_c material Nb oscillated in the range 700 MHz to 3.3 GHz.

INTRODUCTION

We have been studying a single layer superconducting device (1),(2) based on parallel arrays of weak links (3) with a magnetic control mechanism for use as an oscillator. Such a circuit could be very useful in cryogenic sensing systems or in some very low noise systems where cooling is already employed. A typical device is shown in Fig. 1 and consists of 50 links each about 5 microns long by 5 microns wide. Each link is greatly reduced in thickness to provide the desired behavior discussed elsewhere (1), (3), (4). The IV curves are hysteretic and have significant non-linearities at sufficiently high drives. An example IV curve is shown in Fig. 2a. As shown in Fig. 2b, a control current, either injected into the device or running through an adjacent control line, changes the IV curve. This has been attributed to a change in flux density in the device while it is biased in a flux flow region. The flux flow region shown on the IV curve is the region of biasing for most applications including oscillators. It is in this region that the control line has its most significant effect. The control signal effect can be modeled by a current controlled voltage source since a current in the control line causes a horizontal shift of the flux flow section of the IV curve for small control currents. Biasing is done with a current source which is readily realizable because of the very low device impedances.

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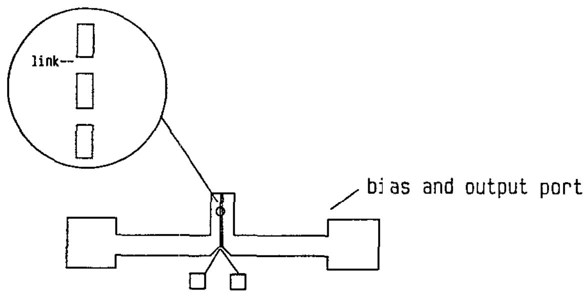

Fig. 1. A typical single layer device to be used in the oscillator circuit. The drawing is not to scale in the interests of clarity. The control line is typically separated from the device body by 15 microns and the control line is about 20 microns wide.

Many measurements have been made on the device including S- parameter measurements. These measurements indicate that the device discussed is indeed active and is probably capable of gain in the appropriate impedance environment (2). The input and output impedances of the controlled device are very low: input on the order of milliohms, output on the order of ohms. Impedance matching then becomes an important task and output power levels will typically be low. Some impedance levels can be exploited, in particular the low input impedance is used to advantage in the oscillator design discussed below.

The devices are made of Nb or one of the high T_c materials: YBaCuO, BiSrCaCuO, or TlCaBaCuO. The Nb films are about 40 nm thick and the links are thinned to about 5-10 nm for the operation described above. The patterning and thinning of the Nb devices are done with anodic oxidation (1). Among the high T_c materials mentioned, the Tl compound is most desirable since

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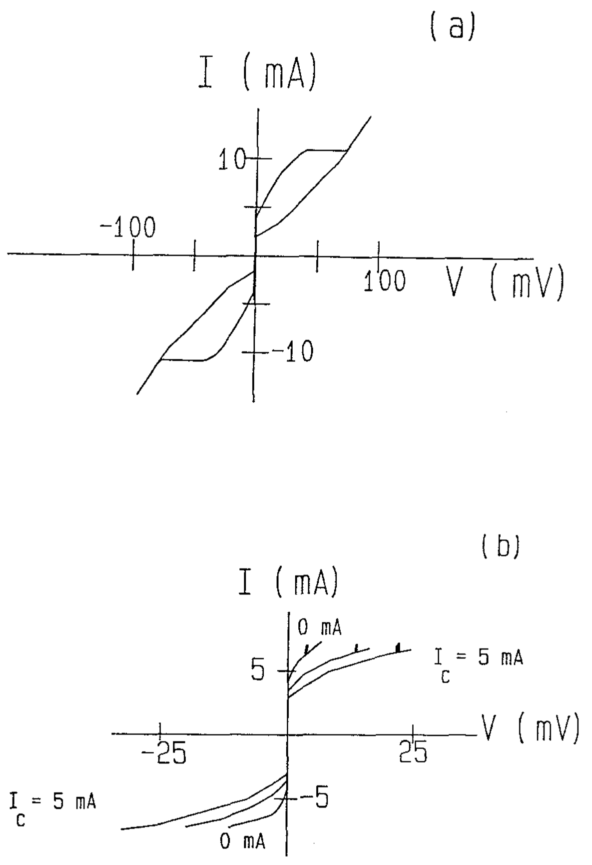


Fig. 2. An IV curve (a) and a version showing the dependence on control current (b). The second curve is expanded to show detail. The device was made of Tl and tested at 77K. The blip shown illustrates the horizontal motion.

even after processing, its T_c is still high enough to allow operation at 77K. The films in this case are about 200 nm thick and the links are thinned to about 20-60 nm. Patterning and thinning for the high T_c materials are done with a timed immersion in a HNO_3 solution.

OSCILLATOR STRUCTURE

Two different topologies have been used and they are shown in Figs. 3 and 4. The oscillator of Fig. 3 uses a resonant feedback circuit between the injection line and the device body. This structure has the advantage of ease of design and the possibility of using any of a number of high-Q superconducting resonators. It does, however, use a large amount of chip area and the tuning of the oscillator could be cumbersome.

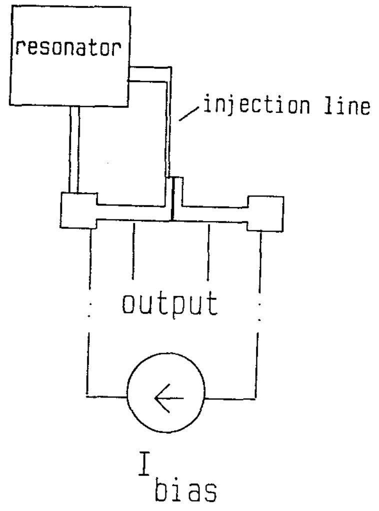
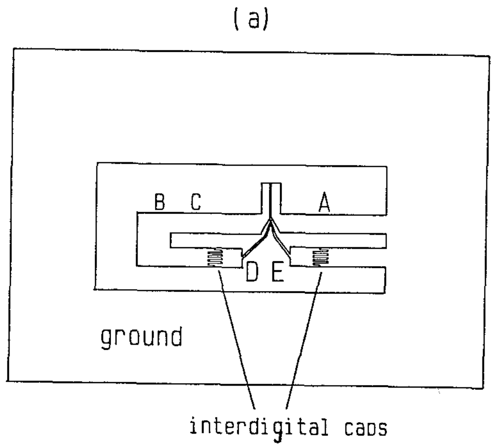


Fig. 3. One oscillator topology tested that uses an injection line-based device. The resonator is also a single film structure: A transmission line resonator.

A potentially more useful structure is shown in Fig. 4 along with its equivalent circuit. The basic circuit for this oscillator, using a generic current-controlled voltage source, is discussed in Clarke and Hess (5). Note that no separate resonator is used in this circuit, it is instead built into the topology. To fit the device discussed above, the circuit uses a current-controlled voltage source and a series resonant circuit. The upper inductor in Fig. 4b represents the control line and hence the current through it is the appropriate controlling quantity. The total inductance is composed of the control line inductance (it is narrow and relatively long) and the internal inductance of the device body. Neither component can be ignored in analyzing the circuit. The largest component of the resistance is the link array: when biased into flux flow, the links do have a finite resistance. The capacitance is essentially provided by a pair of interdigital capacitors shown which also serve as DC blocks. The control line section is DC isolated for tuning purposes that will be discussed shortly. Another purpose of the interdigital capacitors is to dwarf the effect of a parasitic capacitance between the control line and the device body. Since this is a single film structure, the parasitic capacitance is small. By making the interdigital capacitances dominant, however, it is easier to design a circuit with a given oscillation frequency. A design was done with the Microwave Spice program (EEsof, Inc.) and the approximate component values shown in Fig. 4b. (These values are the first terms in the power series expansions.) These components values are arrived at from modeling based on S parameter measurements and from IV curve data.



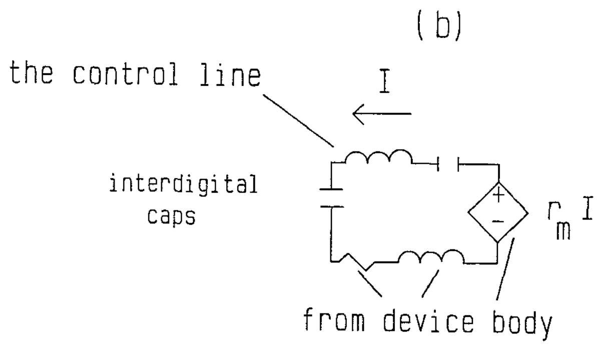
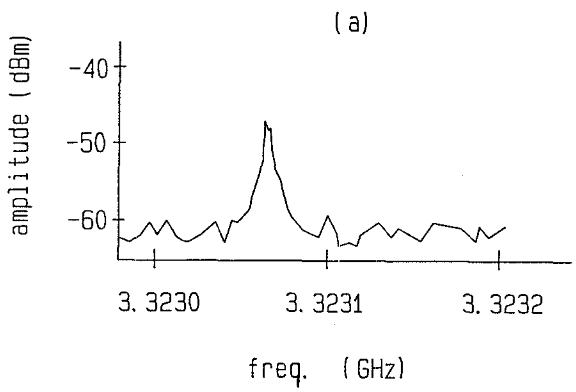


Fig. 4. (a) An oscillator topology that uses a control line- based device. Bias current is driven between points A and B, output is taken from points A and C, and the oscillation frequency can be tuned by driving a low frequency (or DC) current between points D and E. Shown in (b) is the approximate equivalent circuit. The approximate loop inductance = 5nH, loop capacitance = 1pF, loop resistance = .1Ω, transresistance = 17Ω.

This second structure is compact and has greater possibility for tuning. By applying a DC signal to the isolated control line of Fig. 4a, the effective inductance of the device body can be changed significantly (because the bias state of the device has changed) and hence the oscillation frequency will change. The bias point can be changed on either structure to tune the oscillation frequency but the range is not great as will be shown below.

EXPERIMENTAL RESULTS

Both of the above circuits were built with both Nb and TlCaBaCuO and tested at 4.2K and 77K respectively. Several versions were built that operated at lower frequencies (700 MHz-2.5 GHz) but shown in Fig. 5 are measured spectra for devices oscillating near 3.3 GHz. The spectra shown are for devices made of TlCaBaCuO tested at 77K. Higher frequency devices were not designed at this time because of test fixture limitations. The linewidth of the control line based oscillator (Fig. 4a) was smaller than that for the injection line based circuit (Fig. 3) but this is largely because a relatively low-Q coplanar strip resonator was used for the latter circuit. The output power in both cases was near -40 dBm and this could be increased by probably 10 dB if the output were better matched.



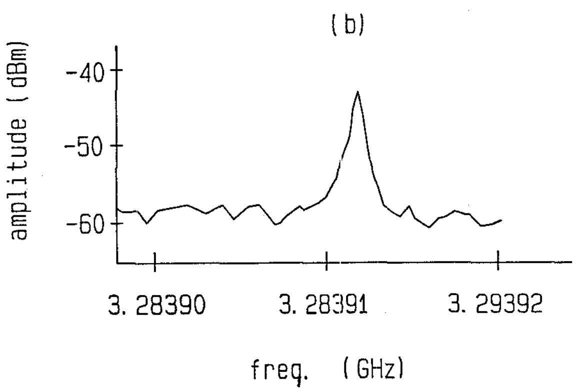


Fig. 5. The measured output spectra of circuits made of TlCaBaCuO and tested at 77K. (a) is for the circuit of Fig. 3 and (b) is for the circuit of Fig. 4a.

When both circuits were tuned with the bias current, the maximum deviation was limited to about 5% of center frequency. When the added DC control current (mentioned above) was used to tune the control line based circuit, a maximum deviation of 20% was achieved. Hence this second topology has a definite advantage in terms of size and tunability. There is yet another method, with more complicated fabrication, that could lead to much greater tunability (6). If a heater line were placed over the control line, the penetration depth and hence the inductance in the model could be changed over a very wide range. With such a scheme, the range could be increased to well over an octave theoretically.

CONCLUSIONS

The oscillator designed above can work at least in the low microwave range. The maximum oscillation frequency, at least at present, is setup limited. The current tunability limit is about 20% although there is at least one modification that should allow a range of more than an octave. Most importantly, the circuit can be fabricated from a single film of a high T_c or a low T_c superconductor. The devices used are much easier to make than the usual tunnel junctions (3) and allow the use of high T_c materials which is currently very difficult to use in a multilayer structure. This allows a reasonable power output at 77K in a very small package.

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