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# Report on a SQUID made from High Temperature Superconductor

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## ABSTRACT

This report summarises the manufacture and performance of a thin film SQUID made from yttrium barium copper oxide on a neodymium gallate bicrystal substrate. At 77 K the device displayed large amplitude (75 $\mu$ V) quasi-periodic response to magnetic field. The deviation from a regular periodic response is ascribed to focussing effects. The noise output was determined as  $1.2 \times 10^{-3} \Phi_0/\sqrt{\text{Hz}}$  at 1 Hz.

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Approved on behalf of Chief Executive, NPL,  
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## 1 BACKGROUND

A SQUID is a loop of superconducting material containing a number of "weak links". The loop can only carry current in quantised amounts, such that it contains an integral number of magnetic flux quanta. The weak links allow flux quanta to enter or leave the loop relatively easily. The flux quantum has the value  $h/2e$  ( $2.07 \times 10^{-15}$  Wb). SQUIDs can form the basis of extremely sensitive sensors for magnetic field, or any physical quantity which can be made to influence a magnetic field.

SQUIDs operating at 77 K, based on high  $T_c$  superconductors, may create a greatly enlarged market compared with devices operating at liquid helium temperature.

The field of superconducting electronics and SQUIDs is well covered in reference 1

## 2 APPROACH

We have used, as the weak link (or junction), the combination of a well-defined grain boundary and well-defined local strain in a thin film. This technique, based on an anisotropic bicrystal substrate, was developed at NPL and is described more fully elsewhere (2).

The superconductor used was  $\text{YBa}_2\text{Cu}_3\text{O}_{7-x}$  ( $T_c$  up to 92 K), deposited as a film approximately 300 nm thick by the inverted cylindrical magnetron technique (3).

Three SQUIDs were created in the same film by using the pattern shown in figure 1. Patterning was done by standard photolithography, followed by etching in dilute orthophosphoric acid. Each device has a loop area of  $50 \times 50 \mu\text{m}$ . The weak links (2 in each SQUID) are in the narrow arms of the loops, which pass over the bicrystal boundary. The track widths here are either 5, 3, or  $2 \mu\text{m}$ .

Current and voltage leads were attached by indium solder to silver pads evaporated onto the unpatterned areas of superconductor, so that the  $3 \mu\text{m}$  SQUID was connected.

## 3 RESULTS

The properties of the  $3 \mu\text{m}$  SQUID was measured in the Centre for Basic Metrology in the Division of Quantum Metrology, by Dr J.C.Gallop and Ari Ercole, a vacation student. All measurements were done at 77 K.

Figure 2 shows the current-voltage characteristic across the SQUID - essentially two junctions in parallel. The combined critical currents are about  $150 \mu\text{A}$ , and the normal state resistance about  $0.4 \Omega$ .

Figure 3 shows the voltage across the SQUID as a function of magnetic field, with the SQUID biased by a current of  $350 \mu\text{A}$ . Ideally this would be sinusoidal with the period determined by the flux quantum divided by the area of the SQUID loop.

This result shows modified SQUID behaviour, with the effective loop area reduced and poorly defined. The dominant period, approximately  $40 \mu\text{T}$ , corresponds to a loop area of  $7 \times 7 \mu\text{m}$ . The periodicity therefore differs from that expected by a factor of about 50. A careful search for periodicity near the expected scale of  $0.8 \mu\text{T}$  found no evidence for any. The explanation is likely to be a focussing effect caused by the large area of superconductor surrounding the loop. This will tend to expel or trap magnetic flux away from the loop, and could very well account both for the effective area reduction and the deviation from sinusoidal response. Similar effects are not unusual in other SQUIDs (4), but focussing theory is as yet very inexact, and designs tend to be developed empirically.

The voltage amplitude, one of the factors determining the final performance of a device, at 75  $\mu\text{V}$  compares well with other results. These traces were reproducible, and the SQUID was cycled between 77 K and 300 K several times without adverse effects.

The noise output of the SQUID was estimated at low frequencies ( $<10$  Hz) using a dynamic signal analyser in a well screened environment. A more detailed description of the experimental conditions is given in reference 5. At these frequencies  $1/f$  noise predominates, and a value of  $1.2 \times 10^{-3} \Phi_0/\sqrt{\text{Hz}}$  was obtained at 1 Hz. This is a very reasonable figure compared with typical results for high temperature superconductor SQUIDs.

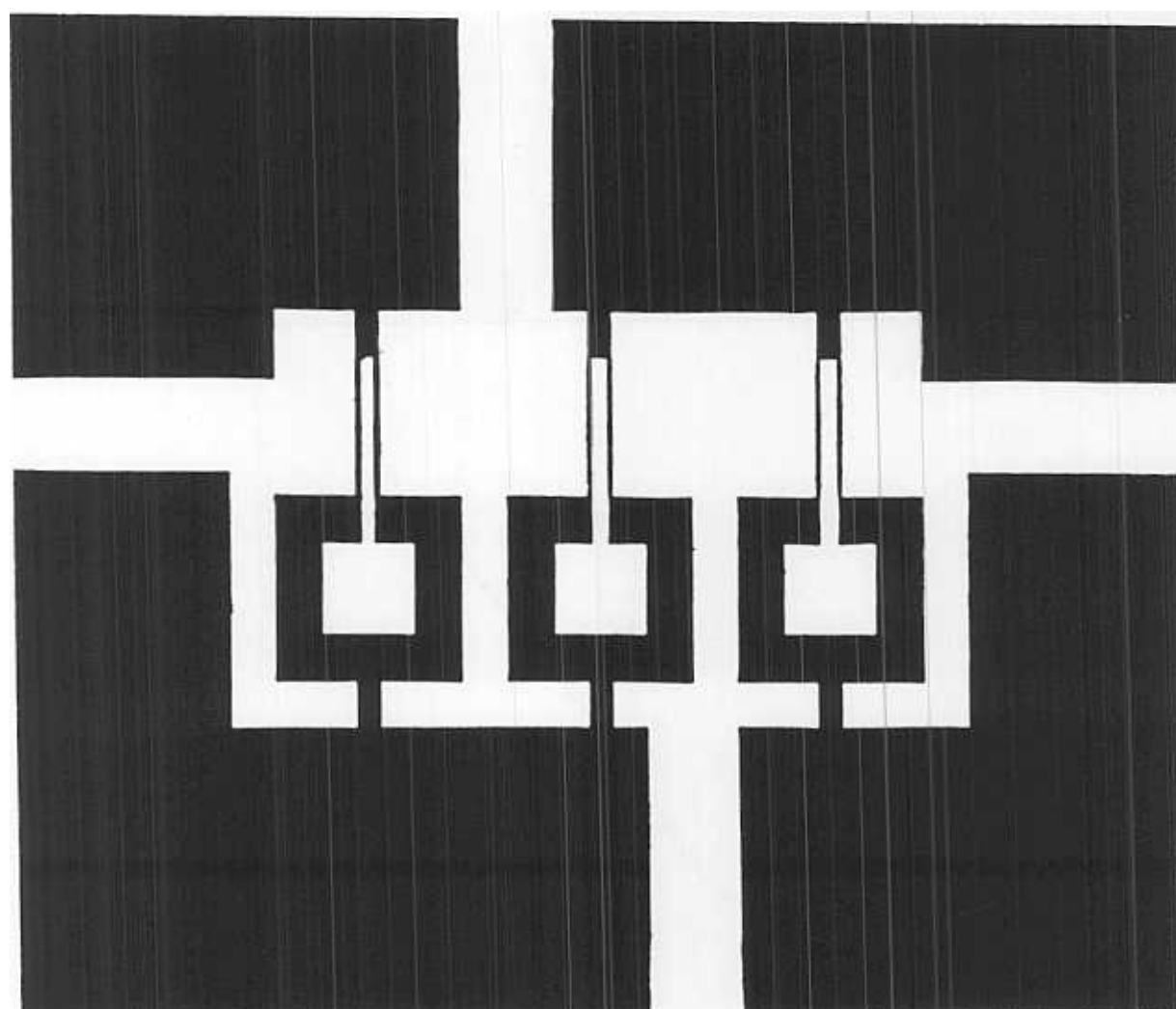
#### 4 CONCLUSION

SQUID behaviour at 77 K has been demonstrated in a thin film device. The device was reasonably consistent and robust, and could form the basis of a functional instrument. This would need to incorporate a superconducting flux transformer, a coil requiring multilayer thin films presently beyond our capabilities. Useful and simple development work could be done on the basic SQUID pattern to improve focussing effects, and on the optimising of parameters available within the anisotropic bicrystal technique.

#### REFERENCES

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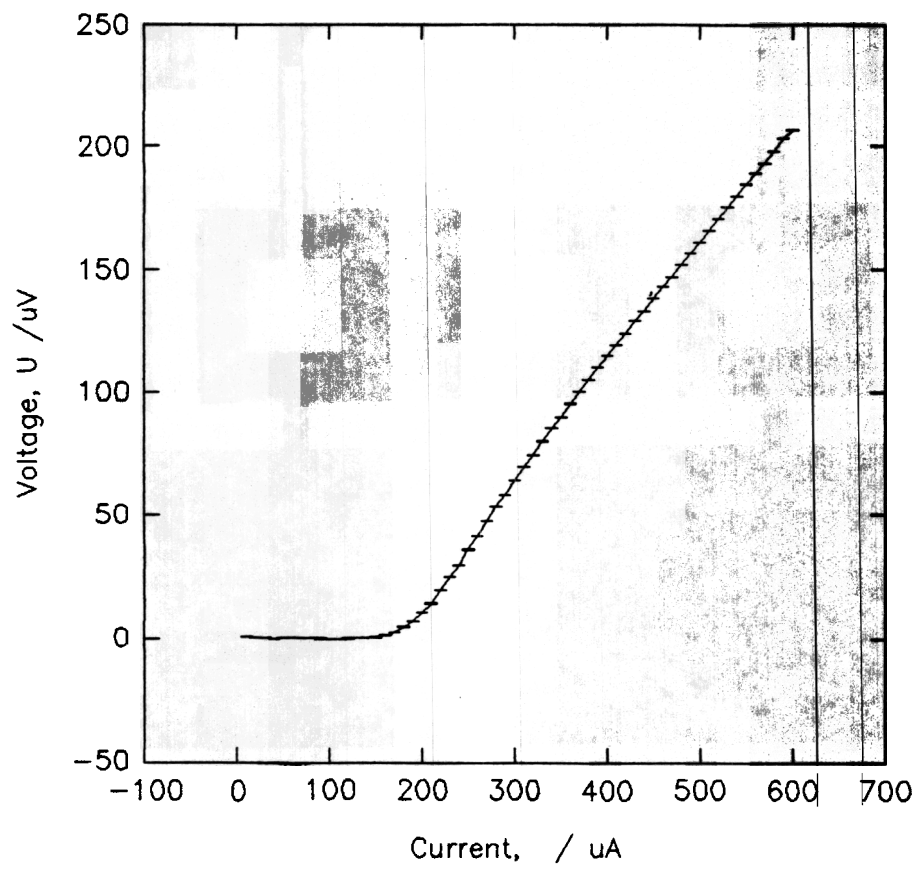
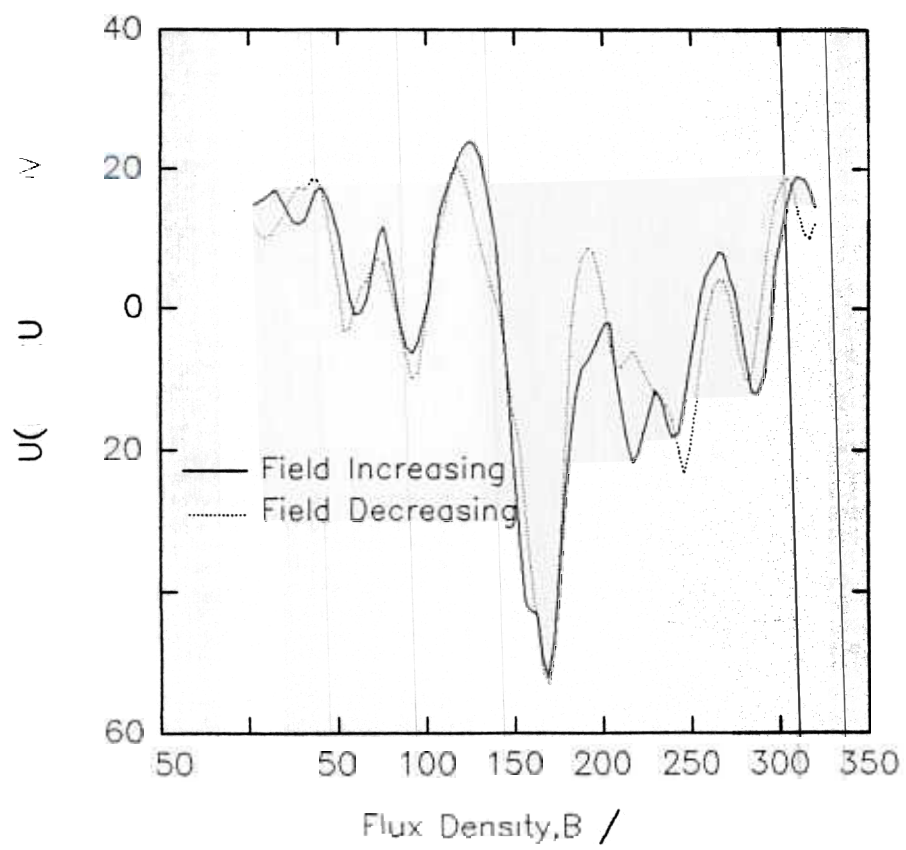


Figure 2

SQUID current-voltage characteristic.



Figure

SQUID response to magnetic field  
The current bias is 350  $\mu\text{A}$ .