



HAL
open science

Realization of high Tc DC SQUIDS. Characterization on a broad range of temperature

Christophe Dolabdjian, Didier Robbes, C. Gunther, Marc Lam Chok Sing, R. Desfeux, Daniel Bloyet

► To cite this version:

Christophe Dolabdjian, Didier Robbes, C. Gunther, Marc Lam Chok Sing, R. Desfeux, et al.. Realization of high Tc DC SQUIDS. Characterization on a broad range of temperature. *Journal de Physique III*, 1994, 4 (4), pp.621-625. 10.1051/jp3:1994151 . jpa-00249129

HAL Id: jpa-00249129

<https://hal.science/jpa-00249129>

Submitted on 4 Feb 2008

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

Classification
Physics Abstracts
85.25

Realization of high T_C DC SQUIDS. Characterization on a broad range of temperature

C. Dolabdjian, D. Robbes, C. Gunther, M. Lam Chok Sing, R. Desfeux (*) and D. Bloyet

Laboratoire d'Electronique et d'Instrumentation, ISMRA, Boulevard du maréchal Juin, 14050 Caen Cedex, France

(Received 15 July 1993, revised 10 January 1994, accepted 17 January 1994)

Abstract. — The analysis of different types of Josephson junctions allows us to depict temperature dependences of the critical current $I_C(T)$, the Josephson penetration depth $\lambda_J(T)$ and main SQUID parameters. We show that a DC SQUID can operate on a broad range of temperature, with a current modulation equal to ϕ_0/L in the limit $\beta \gg 1$. The analysis is given within the RSJ model. For this purpose, the usual DC SQUID current biasing circuit is replaced by a voltage controlled system which detects current modulation. This voltage biasing is compatible with modulation technique usually applied to reduce the $1/f$ noise level of the junctions.

Introduction.

We here examine the constraints resulting from the development of DC SQUIDS operating over a broad range of temperature. We show its feasibility with existing high T_C Josephson junctions. DC SQUIDS performances with large and small β parameters are compared on this point of view. Experimental work is based on GBJ (Grain Boundary Junctions) step-junctions SQUIDS. Furthermore, we introduce a voltage biasing system which directly gives the current modulation and is almost temperature independent.

Theory.

The temperature dependence of the critical current of a high T_C junction or, equivalently its IV curve, can be quite well described by an SNS or SNINS type junction model.

The sketch given in figure 1 shows the electrical and geometrical parameters involved in the design of a Josephson junction. The main one is the Josephson penetration depth expressed as

(*) CRISMAT URA 1318 CNRS.

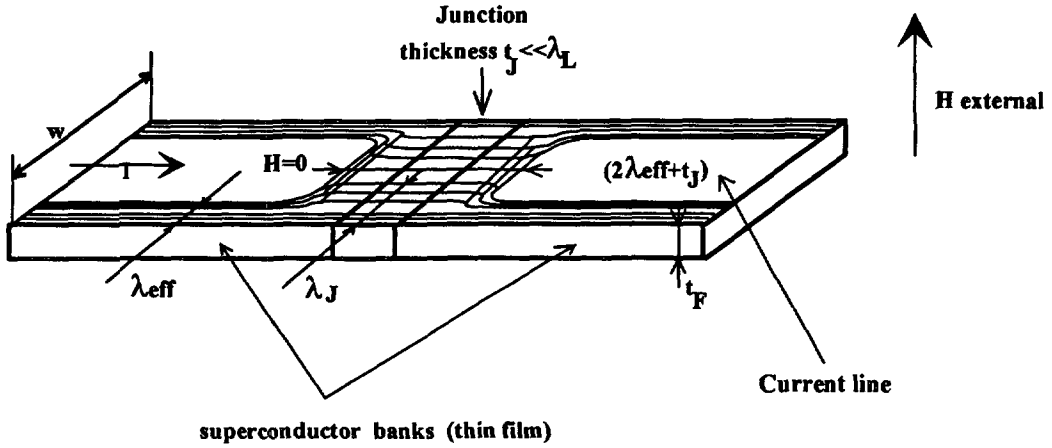


Fig. 1. — Sketch view of electrical and geometrical parameters implied in a Josephson junction.

$\lambda_J^2(T) \approx \frac{\phi_0}{4 \pi \mu_0 \lambda_{EFF}(T) J_C(T)}$, $\lambda_{EFF}(T) = \lambda_L(T) \coth \left(\frac{t_F}{\lambda_L(T)} \right)$ where t_F is the thickness of the film and $\lambda_L(T) = \lambda_0(T) \left[1 - \left(\frac{T}{T_C} \right) \right]^{-1/2}$ is the London penetration depth [1]. Junctions are called narrow or wide depending whether on their width is smaller or larger than $4 \lambda_J$ [2]. The temperature dependence of $J_C(T)$ allows to deduce the width w satisfying the small junction criterion over an expected temperature range (T_L, T_H), w is obviously deduced from the T_L constraints.

From published results [3-5], we have plotted in figure 2 a few $J_C(T)$ dependences from which the maximal width of the junction has been estimated. λ_J plotted in figure 3 is deduced from $J_C(T)$ and its minimum value (at low temperature) defines the main constraint. The width

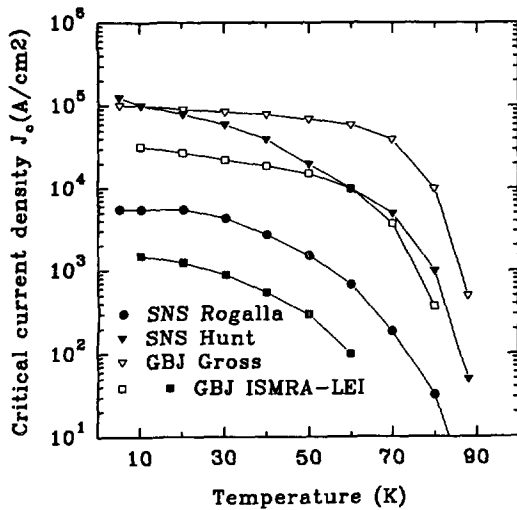


Fig. 2.

Fig. 2. — Measured critical current density $J_C(T)$ (A/cm²).

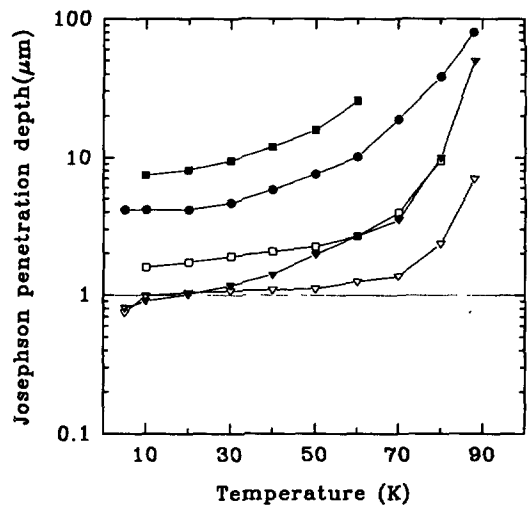


Fig. 3.

Fig. 3. — Josephson penetration depth λ_J (μm) deduced from $J_C(T)$.

of the junctions [3-5] have thus been selected as : $w = \lambda_J$ (10 K), so that w is always smaller than $4 \lambda_J$ in the whole temperature range. This choice determined the critical current value I_C of each junction which are reported in figure 4.

Furthermore, the parameter $\Gamma = I_C \phi_0 / 2 \pi k_B T_H$ must be larger than 10 to avoid the noise rounding effects on the IV characteristic which reduces the SQUID current modulation ΔI . The value are reported in figure 5, expressed as : $\Delta I = 2 I_C / (1 + \beta)$, $\beta = 2 L I_C(T) / \phi_0$ [6] where L inductance of the SQUID was taken at 100 pH. In the high β limit the current modulation $\Delta I(T) = \phi_0 / L$. This case also corresponds to a low rounding noise as I_C is quite important and is therefore suitable for a SQUID operating on a broad range of temperature. On the other hand, a small I_C leads to a drastic decrease of ΔI with increasing temperature and to a significant level of noise.

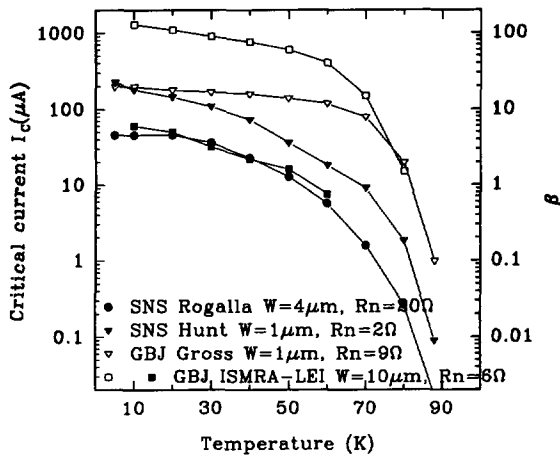


Fig. 4.

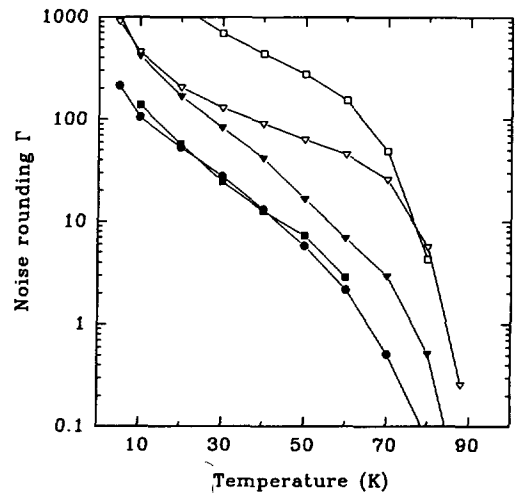


Fig. 5.

Fig. 4. — Critical currents and β parameters of junctions. Their width is specified in the inset with $t_F = 200$ nm ; normal resistance R_N are roughly temperature independent and given in the inset.

Fig. 5. — Noise rounding parameter values associated with junctions of figure 4 as a function of temperature.

Experimental work.

Step-junctions have been realized to validate this concept. The fabrication methods were chosen to be as close as possible to standard thin film fabrication techniques. YBaCuO films are deposited on MgO substrates by laser ablation. The method of forming the edge in MgO substrates is the same as in [7]. We use a standard photoresist as an etch mask and Ar milling process. Au contact pads are sputtered through a mechanical mask for ultrasonic Al wire bonding. Standard photolithography technics are used to pattern the YBaCuO film with wet etching in EDTA. Current modulation ΔI of two home-made SQUIDS with step junctions have been calculated by using an inductance $L = 100$ pH (usual value of our devices). Comparison between theory and experiment figure 6 and figure 7 shows that a better agreement is obtained in the high β limit since the noise rounding effect becomes negligible.

Finally, the last question is that of biasing and detecting system. To detect current modulation a voltage biasing circuit is absolutely necessary. Recently, we proposed a simple,

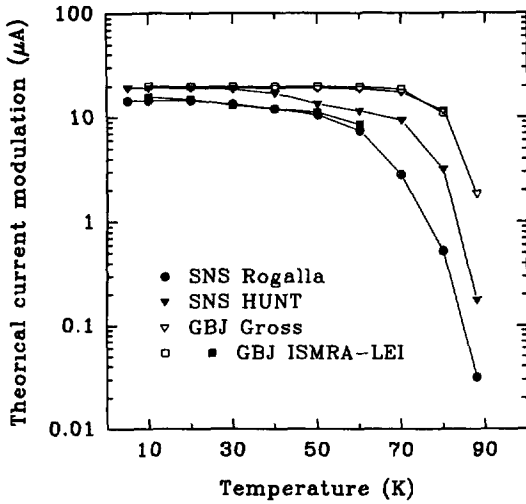


Fig. 6.

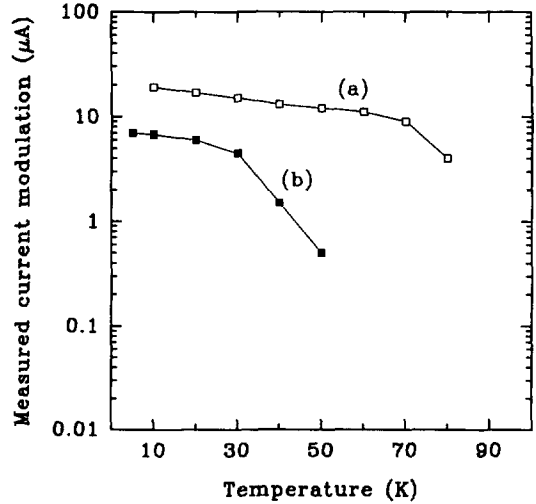


Fig. 7.

Fig. 6. — Calculated current modulation ΔI of SQUIDs.

Fig. 7. — Measured current modulation : (a) high β SQUID, (b) small β SQUID.

low cost, and very low noise voltage regulation of low impedance devices [7] depicted in figure 8.

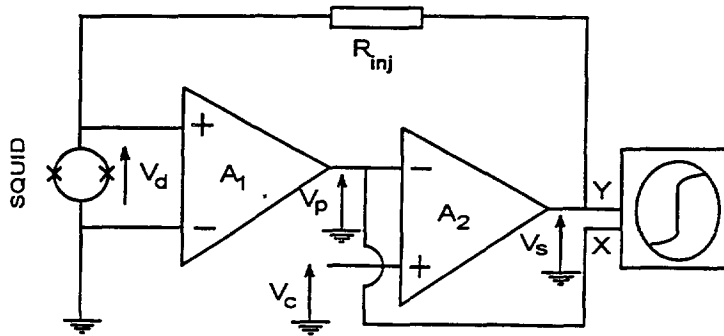


Fig. 8. — Sketch view of the voltage biasing circuit.

The voltage V_d is locked to the reference value V_c by the A_2 stage and a feedback loop. The SQUID modulation ΔI is roughly given by $\Delta V_s / R_{inj}$ and the voltage V_d by V_p / A_1 . Low T_C DC SQUIDs were successfully tested. The white noise level was found to be around some $\mu\phi_0 / \sqrt{\text{Hz}}$, both with the classical current biasing technic and with the voltage controlled biasing system. The current modulation ΔI of our high β SQUID is close to a periodic triangle pattern (period ϕ_0) and the equivalent current noise e_n / r_D can be seen as an equivalent flux noise $S_\phi = \frac{e_n}{r_D} \frac{\phi_0}{2 \Delta I}$, where r_D is the dynamic resistance of the SQUID and e_n is the voltage noise at the preamplifier input, when using this biasing-detecting system of HTS SQUIDs. It

should be emphasized that the two biasing systems are equivalent as far as their input noise level is concerned, but that voltage biasing circuit allows a much broader range of operation in temperature than the current biasing one.

References

- [1] Gross R., Grain boundary Josephson junctions in the high temperature superconductors, to be published *Interfaces Superconducting Syst.*
- [2] Waldram J. R., Pippard A. B., Clarke J., Theory of the current-voltage characteristics of SNS junctions and other superconducting weaklinks, *Philos. Trans. R. Soc. Lond. A.* **268** (1970) 265.
- [3] Hunt D., Foote M. C., Bajuk L., All High T_c edge geometry weaklinks utilizing YBaCuO barriers layers, *Appl. Phys. Lett.* **59** (1991) 1982.
- [4] Gao J., Boguslavski Yu., Klopman B., Terpstra D., Wijbrans R., Gerritsma G., Rogalla H., YBaCuO/PrBaCuO/YBaCuO Josephson ramp junctions, *Appl. Phys. Lett.* **72** (1992) 575.
- [5] Ferrell R. A., Josephson tunneling and quantum mechanical phase, *Phys. Rev. Lett.* **15** (1965) 527.
- [6] Tesche C., Clarke J., dc SQUID : Noise and optimization. *J. Low Temp. Phys.* **29** (1977) 301.
- [7] Friedl G., Roas B., Romeheld M., Schultz L., Wjutzli L., Transport properties of epitaxial YBaCuO films at step edges, *Appl Phys. Lett.* **59** (1991) 2751.
- [8] Dolabdjian C., Robbes D., Lesquey E., Monfort Y., Active voltage biasing of very low impedance devices, *Rev. Sci. Instrum.* **64** (1993) 821.