

**OPEN ACCESS**

## Thermal response of Josephson junction arrays on silicon nitride membranes

To cite this article: J J Zárate and H Pastoriza 2009 *J. Phys.: Conf. Ser.* **150** 012057

View the [article online](#) for updates and enhancements.

### Related content

- [Breakdown of Charge-Vortex Duality in Small Tunnel Junction Arrays with Finite Width](#)  
Ryuta Yagi and Shun-ichi Kobayashi
- [Inductance of Long Intrinsic Josephson Junction Arrays Composed of Misaligned  \$Tl\_2Ba\_2CaCu\_2O\_8\$  Thin Films](#)  
Zhou Tie-Ge, Yan Shao-Lin, Fang Lan et al.
- [Study of improving the thermal response of a construction material containing a phase change material](#)  
A Laaouatni, N Martaj, R Bennacer et al.



**240th ECS Meeting** ORLANDO, FL  
Orange County Convention Center Oct 10-14, 2021



Abstract submission due: April 9

**SUBMIT NOW**

# Thermal Response of Josephson Junction Arrays on Silicon Nitride Membranes

J J Zárate<sup>1</sup> and H Pastoriza<sup>2</sup>

Laboratorio de Bajas Temperaturas and Instituto Balseiro, Centro Atómico Bariloche, Argentina

E-mail: <sup>1</sup>zaratej@ib.cnea.gov.ar, <sup>2</sup>hernan@cab.cnea.gov.ar

**Abstract.** In order to study the vortex dynamics in Josephson junction arrays under temperature perturbations we have build Pb/Cu structures on top of Si<sub>3</sub>N<sub>4</sub> membranes. Membranes with an area of 1 mm<sup>2</sup> and with a thickness of 650 nm were fabricated by anisotropic etching of a silicon substrate previously covered with a low stress nitride film. By e-beam lithography and thermal evaporation we defined two similar SNS Josephson arrays one on top of the membrane and another on the bulk substrate. The heat source was provided illuminating the sample space with a conventional LED placed a few millimeters away from the substrate. Using the superconducting transition of both arrays the thermal response of the system has been characterized obtaining a cut-off frequency of 150 Hz and the power efficiency of our setup.

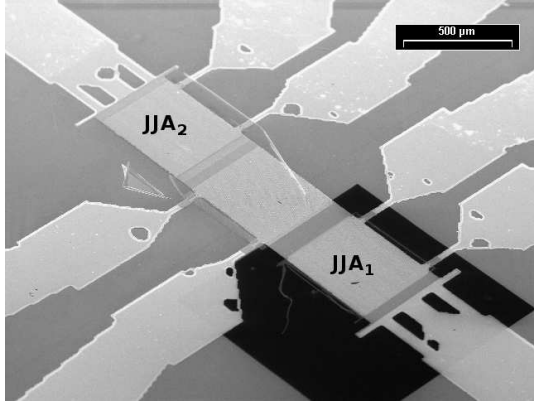
## 1. Introduction

Two dimensional Josephson junction arrays (JJA) have proven to be interesting systems for the study vortex physics. The competition between the repulsive vortex-vortex interaction and the attractive periodic pinning potential due to the discreteness of the array results in interesting forms of vortex phases [1] and dynamics [2]. The capability of arbitrarily change the coupling between superconducting islands during the fabrication bring the possibility of test and simulate different physical models. Most of the experiments performed in JJA are either electrical transport or kinetic inductance measurements. Previous results [3] on asymmetric JJA motivate the study of vortex dynamics in these systems under periodic thermal fluctuations. In this paper we present our design and setup for such experiments. We follow the fabrication techniques widely used in the fabrication of microbolometers and microcalometers. Taking advantage of the microfabrication small mass holders are easily achieved allowing the development of systems with fast thermal responses.

## 2. Experimental Details

Low stress Silicon Nitride membranes of 650 nm in thickness were fabricated from a double coated Si/SiN<sub>x</sub> wafer. Squares of about 1 mm<sup>2</sup> were defined by photolithography and etched with SF<sub>6</sub> plasma in the back side of the wafer. Next, a wet Si anisotropic etch in a KOH solution were used to produce a trough hole in the wafer defining a square SiN membrane in the top side. A Cu/Pb (200 nm/200 nm) bilayer were deposited on the membrane by thermal evaporation. By means of e-beam lithography the superconducting Pb islands were patterned. To be able to characterize the thermal response one JJA were fabricated on the membrane and another outside

and serially connected. In Fig. 1 we show a Scanning Electron Microscope (SEM) image of the sample.



**Figure 1.** SEM image of the sample. The darker part of the substrate corresponds to the SiN membrane. Three samples were fabricated in serial which allows the simultaneous testing response of the JJA on top, and away of the membrane.

All measurements were done in a  $^4\text{He}$  cryostat with a 1K pot. The sample was mounted in vacuum on a temperature controlled Cu sample holder glued with Apiezon N © vacuum grease. A red LED were placed 2 mm above and facing the sample. Modulating the current through the LED we provide an alternating heat source  $Q(t) = \dot{Q}_{\text{light}} \sin(\omega t + \varphi)$  allowing temperature variations in the sample  $T(t) = T_0[1 + A \sin(\omega t)]$ . As the LED become inoperative for temperatures  $T < 30\text{ K}$  it was mounted through a plastic thermal isolation from the  $^4\text{He}$  pot and kept warm by the self heating of a bias current.

### 3. Results

#### 3.1. Response to Continuous Heater

The thermal response of the membrane can be evaluated from measurements of the  $R_1(T)$  of the JJA on the membrane for different power levels of the LED. The variable  $T$  refers to the temperature measured by the thermometer in the sample holder. In Figure 2 we plot  $R_1(T)$  and  $R_2(T)$  (the last one is the resistance of the JJA out of the membrane) for different  $\dot{Q}$  levels. It is clear that when the LED is on the actual temperature of the membrane is higher due to the thermal resistance from the membrane to the substrate.

In order to evaluate the  $\Delta T_1(I_{LED})$  dependence we consider that a fraction  $\gamma$  of the power dissipated by the LED  $P_{LED} = I_{LED}^2 R_{LED}$  is reaching the membrane giving:

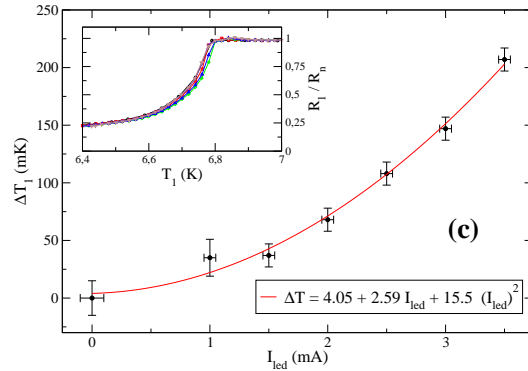
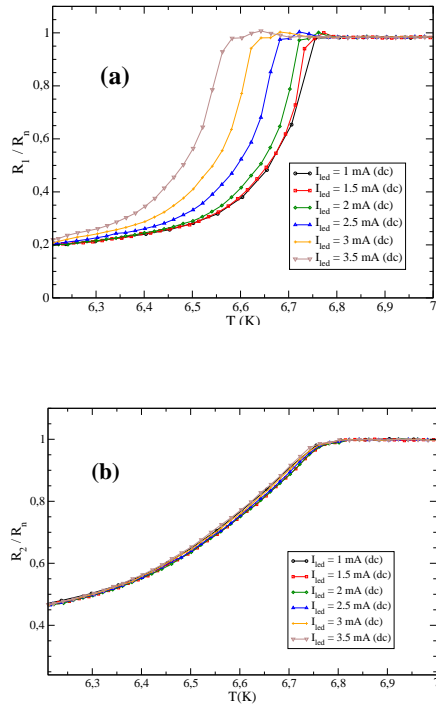
$$\Delta T_1 = (\gamma R_{LED} \mathcal{R}_T) I_{LED}^2 \quad (1)$$

In Fig. 2c we plot  $\Delta T_1$  as a function of  $I_{LED}$  with a quadratic fit. The inset of Fig. 2c shows the same data of Fig. 2a with the temperature scaled as  $T \rightarrow T_1(I_{LED}) = T + \Delta T(I_{LED})$ . The excellent overlap of the curves indicates that the change in the apparent  $T_C$  of the JJA on the membrane is due to the additional heat provided by the LED.

#### 3.2. Frequency response

The thermal model for the system is equivalent to a low pass RC electrical circuit, where the C is given by the thermal heat capacity, and R by the thermal resistance from the membrane to the substrate. It is expected that the membrane will respond to alternate power input up to a frequency given by  $1/RC$ .

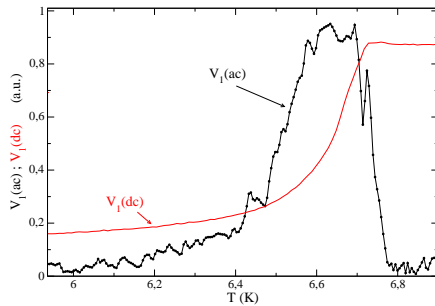
In order to test the frequency response of the system the LED was powered with a constant bias current  $I_{dc} = 2.07\text{ mA}$  plus a alternate current of  $I_{ac}(rms) = 0.583\text{ mA}$ . Biasing the JJAs with a fixed current of  $10\mu\text{A}$  and a fixed frequency of  $f = 83\text{ Hz}$  for LED current, we have



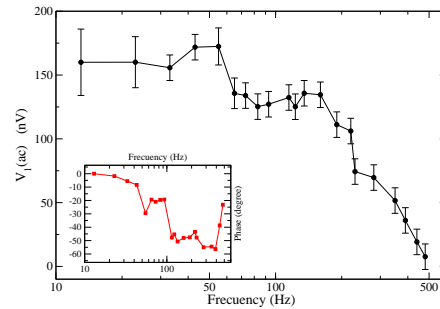
**Figure 2.** (a), (b) Normalized resistance ( $R_n = 355m\Omega$ ) as function of substrate temperature with different currents in LED, for  $JJA_1$  and  $JJA_2$  respectively. (c) Temperature difference in  $Pb(JJA_1)$  transition as function of  $I_{led}$ . In the inset of (c) the same data of (a) are plotted, but with the transformation  $T \rightarrow T_1(I_{led}) = T + \Delta T_1(I_{led})$ .

measured simultaneously the alternate and continuous voltages on the  $JJA_1$  as a function of temperature with a lockin amplifier and a nanovoltmeter respectively. These data are plotted in Fig. 3.

In Fig. 4 we have plot the measured  $V_{ac}$  as a function of the frequency of the current in the LED for a fixed temperature of  $T = 6.65$  K. At low frequencies the response is almost constant with a saturation value of  $\lim_{(f \rightarrow 0)} V_1(ac) \simeq 160$  nV. At high frequencies a cutoff is observed for a frequency of  $f'_c \simeq 150$  Hz with finite response up to 500 Hz.



**Figure 3.** Voltage on  $JJA_1$  as a function of reference temperature  $T$ . Clearly  $V_{(ac)}$  is proportional to  $\frac{dR_1(dc)}{dT}$  indicating that the alternate power in the LED is producing a constant alternate temperature change in the JJA.



**Figure 4.** Voltage  $V_1(ac)$  as a function of frequency for a reference temperature of  $T = 6.65$  K; LED currents  $I_{dc} = 2.07$  mA, and  $I_{ac}(rms) = 0.583$  mA.

#### 4. Conclusions

We have characterized the thermal behaviour of a Josephson Junction Array on a Silicon Nitrate membrane. Using a conventional LED as irradiating heat source we have been able to obtain temperatures differences between the membrane and the substrate of 200 mK at 6 K of sample temperature. The frequency dependence agrees with the thermal model of the system with a frequency cutoff of 500 Hz.

#### References

- [1] Franz M and Teitel S 1995 *Phys. Rev. B* **51** 6551–6574
- [2] Marconi V I, Candia S, Balenzuela P, Pastoriza H, Domínguez D and Martinoli P 2000 *Phys. Rev. B* **62** 4096–4104
- [3] Shalóm D E and Pastoriza H 2005 *Phys. Rev. Lett.* **94** 177001