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# Fabrication of robust superconducting granular aluminium/palladium bilayer microbolometers with sub-nanosecond response

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**Abstract**. We provide a convenient recipe for fabricating reliable superconducting microbolometers as acoustic phonon detectors with sub-nanosecond response, using image-reversal optical lithography and dc-magnetron sputtering, and our recipe requires no chemical or plasma etching. Our approach solves the traditional problem for granular aluminium bolometers of unreliable (i.e., non-Ohmic) electrical contacts by sequentially sputtering the granular aluminium film and then a palladium capping layer. We use dc calibration data, the method of Danilchenko *et al*. [1], and direct nanosecond-pulsed photoexcitation to obtain the microbolometer's characteristic current, thermal conductance, characteristic relaxation time, and heat capacity. We also demonstrate the use of the deconvolution algorithm of Edwards *et al.* [2] to obtain the phonon flux in a heat pulse experiment with nanosecond resolution.

## 1. Introduction

In studies of phonon transport in solids [3], the need for time resolution of less than 1 μs [4] requires that the bolometer be operated in a constant bias-current mode. Superconducting (SC) granular aluminium (GA) microbolometers are often employed for this application with typical response times ranging from 20-100 nanoseconds [5,6,7]. A deconvolution algorithm has been developed to improve the time resolution to approximately 10 ns [2]. SCGA microbolometers however do have shortcomings, including their fragility [8], the difficulty in making reliable Ohmic contact to the superconducting films [9], and their relatively slow response (compared to niobium hot electron bolometer [10]). We report on a convenient recipe for the fabrication of GA microbolometers that incorporates a novel palladium capping layer. The addition of the palladium capping layer produces three noticeable improvements to SCGA microbolometry: (1) a surprising reduction in response time to sub-nanosecond (temperature- and bias current- dependent), (2) easily-made Ohmic contacts, and (3) robust durability with no noticeable degradation or performance change after repeated thermal cycling between room- and liquid helium- temperatures. We attribute the latter two improvements to the prevention of the oxidation of the surface of the GA by the palladium capping layer.

## 2. Fabrication recipe for SC GA/Pd bilayer microbolometers

The microbolometers have been patterned on polished 0.50 mm thick [100] float zone Si:B (30-60 Ω-cm) die of dimension 12 mm x 16 mm. The microbolometers are each of nominal thickness 80 nm with an active region consisting of a 10 μm x 20 μm GA/palladium bilayer that links two larger overlying 1 mm x 2 mm chromium/gold contact pads (nominal thickness 140 nm). We fabricate the bolometers using an all lift-off process with image-reversal optical lithography employing *AZ 5214E* photoresist and *AZ Developer*, as partially described in the literature [11].

We use a load-lock dual-target dc-magnetron sputter deposition system retrofitted with an oxygen lecture bottle and a precision needle valve arrangement. All metal films are sputtered at a dc-magnetron power of 400 W in an 8.5 mTorr argon plasma with an argon flow rate of 28 sccm through the chamber. For the GA deposition, the chamber is evacuated to a base pressure of 1 µTorr, oxygen is introduced and carefully adjusted to a pressure of 170 µTorr, then argon is introduced and the plasma struck; Al is then sputtered to a nominal thickness of 80 nm, immediately followed by a palladium film of nominal thickness 5 nm, sputtered from a second target prior to breaking vacuum. Test runs are first made on clean glass cover slips in order to verify that the resulting room temperature resistivity of the sputtered GA/Pd bilayer is in the range 25-50 µOhm-cm, as measured with a portable four-point probe. Lift-off is easily accomplished by immersion in an acetone ultrasonicated bath for 30 seconds. Subsequent patterning of the chromium/gold contact pads, spaced 20 µm apart and with the midpoint of the opening between the two pads centered on top of the 1 mm long GA/Pd bilayer, then completes the fabrication. Figure 1 shows the microbolometer.

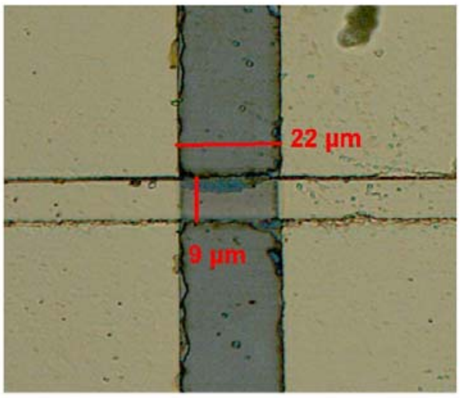


**Figure 1.** Optical micrograph of a portion of the microbolometer.

## 3. Characterization of the SC GA/Pd bilayer microbolometers

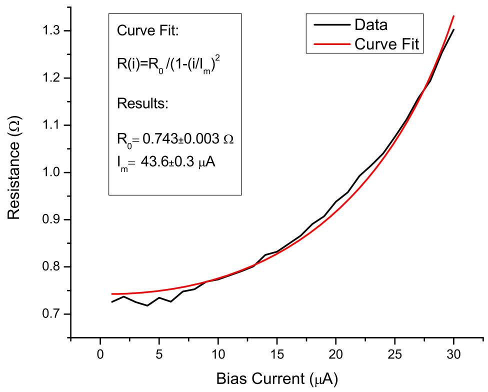


**Figure 2.** (color online) Curve fit as per [1] to to obtain the bolometer's characteristic current $I_m$ =43.6 µA at 1.759 K.

When linear changes of the signal voltage of a superconducting bolometer under the condition of constant biasing current $i_0$ are considered, the response to a given time-dependent energy flux is completely determined by the bolometer's sensitivity parameter α, characteristic current $I_m$, and characteristic relaxation time Λ (at zero bias-current, Λ = τ [= C/G]) [1,12]. From measurements of the latter three parameters, the heat conductance *G* and heat capacity *C* can then be estimated. The frequency-dependent absorptive responsivity *R*(ω) can then also be estimated [7]. Measurements of the bolometer resistance-current calibration curves for a discrete set of bath temperatures (Figure 2 shows one at T=1.759 K) have been collected using a 4-wire technique, and the transition temperature is near 1.8 K, in agreement with previous investigations of the superconductivity of GA alone [13]. The Pd capping layer is apparently sufficiently thin that there is no substantial suppression of the SC transition of the underlying GA layer due to the proximity effect [14]. Figure 3 shows the bolometer response (at two different temperatures and bias currents) to photoexcitation with an attenuated nanosecond-pulsewidth JDS *NanoGreen* NG-10320-010 mini-YAG laser; measured τ's are <0.74 and 2.7 ns, respectively. The relevant operational parameters for our SC GA/Pd microbolometer are listed in Table 1 below. Bias current is supplied through an Avtech *AVX-T* bias tee (<60ps risetime), the ac-coupled signal voltage is amplified by a 1 GHz Ortec *9306* (30-dB) pulse amplifier, and signal averaged for 4000 pulses with a 1 GHz LeCroy *WavePro950* digital oscilloscope. The effective risetime of the bolometer signal recovery electronics is 400 ps. For comparison, the mini-YAG signal has also been acquired by a Newport *818-BB-20* Si PIN diode detector (risetime <200 ps) and an SRS boxcar (245, 250, 255, 280 modules) signal averager with 3.5 GHz bandwidth.

**Table 1.** Parameters of the SC GA/Pd Bilayer Microbolometers (See [1,7] for definitions)

| | | | |
|---|---|---|---|
| $T_S$ | 1.757 K | 1.791 K | <u>Note</u>: At 1.757 K, our *G* is somewhat smaller than a calculation $9.6 \times 10^{-7}$ W/K, using the active area of the microbolometer and the published thermal boundary resistance between pure aluminium and silicon [15] at 1.8 K. Our *C* is much smaller (36x) than a calculation $6.6 \times 10^{-15}$ J/K, obtained from the published specific heat capacity for GA (sample A of [16]) near 1.8 K (153 $\mu$J $g^{-1}$ $K^{-1}$), and the mass of the active area of our bolometer ($4.3 \times 10^{-11}$ g). At 1.791 K, using G=1.10 x $10^{-7}$ W/K and *C*=1.85 x $10^{-16}$ J/K scaled by $(1.791/1.757)^3$, results in a predicted $\Lambda$ ($\tau$) of 2.0 (1.8) ns. |
| $I_b$ | 20 μA | 10 μA | |
| $R_b$ | 0.91 Ω | 4.3 Ω | |
| $I_m$ | 43.6+/-0.3 μA | 31.0+/-0.9 μA | |
| G\| $\theta_0$ | 2.98 x $10^{-7}$ W/K | 1.10 x $10^{-7}$ W/K | |
| α\| $i_0$ | 131+/-5 Ω/K | 114+/-3 Ω/K | |
| Λ (τ) | <0.94 (**0.74** ) ns | 3.2 (2.9) ns | |
| C | <1.85 x $10^{-16}$ J/K | See <u>Note</u>: | |
| $R(I_b,T_S)$ (f=0) | 1.3 x $10^4$ V/W | 1.2 x $10^4$ V/W | |
| $R(I_b,T_S)$ (f=1 GHz) | >2.2 x $10^3$ V/W | >6.0 x $10^2$ V/W | |

The slower response in Fig.3 occurs at a higher temperature 1.791 K and results from a smaller *G* (1.1 x $10^{-7}$ W/K), as determined from a fit to the calibration data at 1.791 K (not shown). We have used *LabView* to implement the algorithm of Edwards *et al.* [2] using our calibration data, and

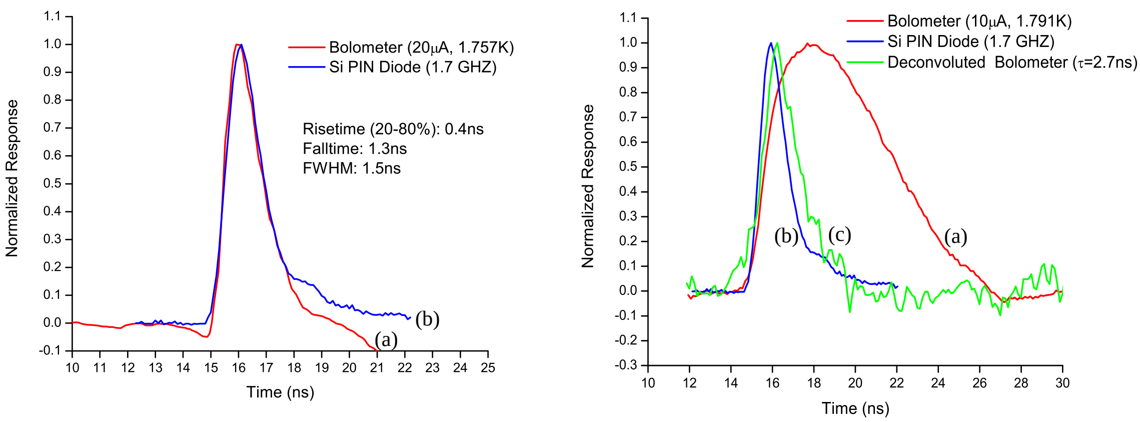


**Figure 3**. (color online) *Left:* Bolometer (a) and Si PIN diode (b) responses to same photoexcitation. Bias current 20μA, T=1.757. <u>Note</u>: τ<0.74 ns. *Right:* bolometer (a), Si PIN diode (b), and deconvoluted bolometer (c) responses to same photoexcitation. Bias current 10μA, T=1.791 K. Note τ=2.7 ns

our values of *G* and τ (2.7 ns in this case) to deconvolute the bolometer signal to obtain the incident power. We note that deconvolution approximately recovers the laser temporal profile.

We have also performed a heat pulse experiment. Pulsed mini-YAG laser radiation is focused (50μm diameter) and partially absorbed in a niobium film fabricated on the front face of the 0.5 mm die opposite the bolometer. Figure 4 shows the microbolometer signal and deconvoluted phonon flux corresponding to the arrival of [100] longitudinal (ballistic) and transverse (ballistic and diffusive) acoustic phonons. The phonon pulsewidths are comparable to the laser pulsewidth.

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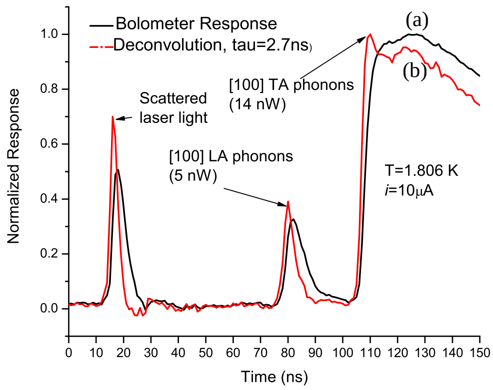


**Figure 4.** (color online) Normalized bolometer response (a) and deconvoluted absorbed power (b) in a heat pulse experiment. Note: Upon deconvolution TA phonon arrival can be clearly resolved and ballistic LA and TA time-of-flights agree (to 1%) with those expected for a 0.544 mm thick substrate; the phonon pulse widths are comparable to the laser pulse excitation. Phonon focusing accounts for the increased TA peak height and a diffusive TA tail is observed.

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