

Fabrication Technology for Single Electron Transistors and Submillimeter Detectors

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ABSTRACT

We describe efforts to develop a robust fabrication technology for making submillimeter detectors integrated with single electron transistors as readout amplifiers. This work will make a fundamental and critical contribution to the development of new classes of imaging detector arrays with photon-counting sensitivity in the submillimeter, and intrinsic energy resolution in the UV/optical and x-ray.

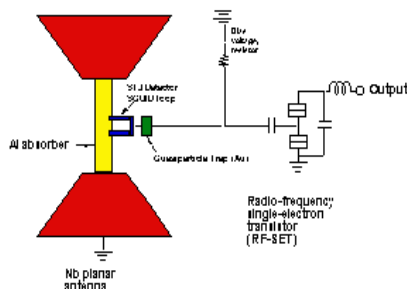
INTRODUCTION

The goal for this work is to develop a photon-counting detector array for submillimeter astronomy. This detector would be 100 to 1000 times more sensitive than current bolometers such that one could reach the photon statistics for narrow bandwidths and low background. One proposed concept is the Single Quasiparticle Photon Counter or SQPC [1]. This is a photoconductor direct detector that couples a superconducting tunnel junction detector to a RF-SET [2]. The RF-SET (Radio-Frequency Single Electron Transistor) is a very sensitive amplifier that can sense the charge of a single electron. Thus, the RF-SET can amplify the small photocurrent generated in a superconducting tunnel junction detector by a single submillimeter photon. Both the detector and RF-SET can be operated at 100 mK so a compact, low power, multiplexed readout array can be fabricated. The RF-SET multiplexed readout is described in these proceedings by Stevenson et al. [3], and a good overview of submillimeter and far-infrared photon-counting detectors is summarized in these proceedings by Schoelkopf [4].

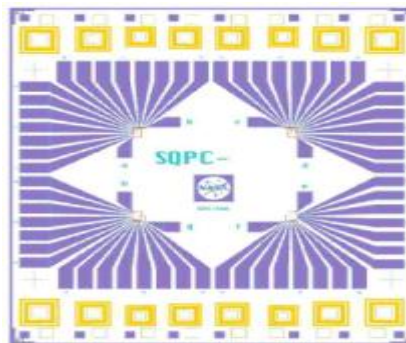
SQPC CHIP DESIGN

[Figure 1](#) shows a schematic of the SQPC. The antenna couples submillimeter photons to an Al superconducting absorber strip, and these photons generate quasiparticles in the absorber strip. The quasiparticles tunnel through the SIS (superconductor-insulator-superconductor) tunnel junction, and the photocurrent is measured by the RF-SET. The quasiparticles are confined to the Al strip by the higher gap Nb superconducting antenna. A SQUID loop suppresses the Josephson supercurrent to achieve a low dark current, which is the limit of sensitivity for the detector. A quasiparticle trap (normal metal) promotes diffusion towards the SET. The layout of the SQPC chip is shown in [Figure 2](#).

Single Quasiparticle Photon Counter - SQPC



[Figure 1](#)



[Figure 2](#)

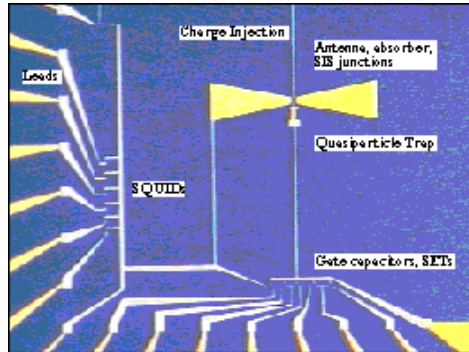
The antenna, detector, and SET are contained in 4 fields, which are fabricated with electron beam lithography and Al double

angle evaporation techniques. The inductor array on two sides of the chip is used for the readout and multiplexing [3]. There are 68 bonding pads and leads to allow a variety of device structures to be tested. The goals of this SQPC design were (1) Demonstrate a detector photoresponse (2) Measure dark current as a function of tunnel junction area and junction resistance (SQUID loops) (3) Optimize SET parameters for low noise by varying the junction resistance and input gate capacitance and (4) Fabricate SETs for multiplexing and operation with charge-locked loops.

FABRICATION OF SQPC CHIP

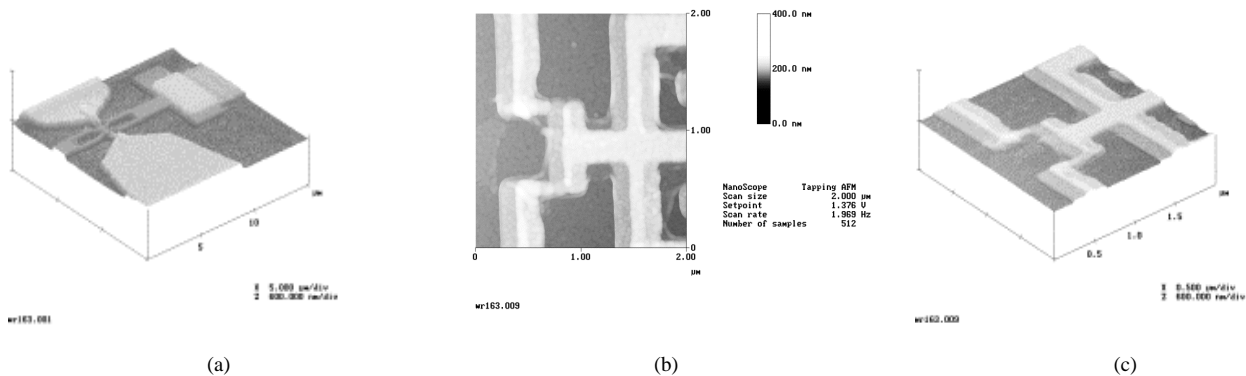
Fabrication of the SQPC chip was done at both NASA Goddard and Chalmers University. The optical fabrication steps were done at Goddard, and the electron beam lithography and Al deposition steps were done at Chalmers. Four inch wafers of SiO₂ (500 nm)/Si were used and each wafer contained ~ 70 SQPC chips. For the optical lithography, three masking and thin metal film deposition steps were done. In the first step, Cr/Au (10/50 nm) was sputter deposited for the leads and quasiparticle traps.

Chemical etching of the Au and Cr was done to achieve a sloped edge for good step coverage and contact. For the second step, Nb/Au (50/20 nm) was sputtered deposited for the antenna, inductor coil array, and the electron beam lithography alignment marks. The thin film of Au on Nb was used in order to make a low resistance contact to the Al film deposited in the electron beam lithography step. Chemical etching of the Au and reactive ion etching of the Nb was done to obtain a good edge profile (15 degrees) for good step coverage of the thin (65 nm) and narrow (33 nm) Al absorber strip between the antenna. Finally, a thick Au film (150 nm) was deposited on the pads for wire bonding. The electron beam lithography and Al thermal evaporation was done to define the SET, absorber strip, SIS tunnel junctions, SQUID, gate capacitor, and interconnects. Double angle evaporation of Al (25/40 nm) with oxidation was used to make the Al/AIO_x/Al tunnel junctions. Fabrication of the SETs was done last in order to reduce potential damage to the SET. [Figure 3](#) shows one of fields of the fabricated SQPC chip.



[Figure 3](#)

The field contains an antenna/detector, SETs with 5 different gate capacitors, SQUID loops with 6 different junction areas, a charge injection line for the detector, and leads to the bonding pads. [Figure 4](#) shows AFM images of the antenna, absorber strip, SIS tunnel junctions, SQUID loops, quasiparticle trap and one of the SETs.



[Figure 4:](#)

RESULTS AND FUTURE WORK

A number of results were achieved from this work. First, all device structures were fabricated. Second, the inductor coil array was tested [3]. Third, a low contact resistance was achieved for the Al/Au interfaces, including the Al absorber strip to the antenna. Depending on which leads were chosen, a resistance between 1000 and 1400 ohms was measured in a two wire test between connections on the bonding pads and electrical paths through the antenna and absorber strip. Finally, good alignment of the electron beam pattern (~ 250 nm) to the optical patterns was achieved.

Work is in progress to meet the critical goals of this project. More devices need to be fabricated for the electrical measurements. The tunnel junction resistances for the SETs (~200 k Ω) and the detector (~30 k Ω) need to be achieved. The dark current through the SQUID loops will be measured. For detector performance, injected charge into the absorber strip will first be measured. Finally, a photoconductor response from the SQPC will be measured.

ACKNOWLEDGEMENTS

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