Fabrication of phononic-isolated kinetic inductance detectors

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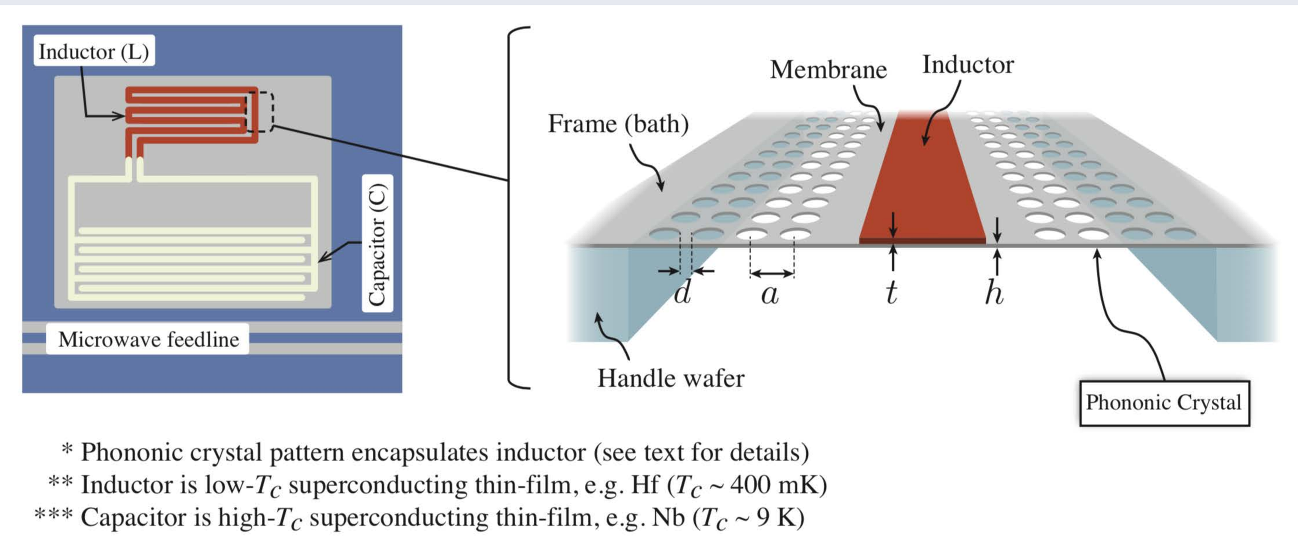
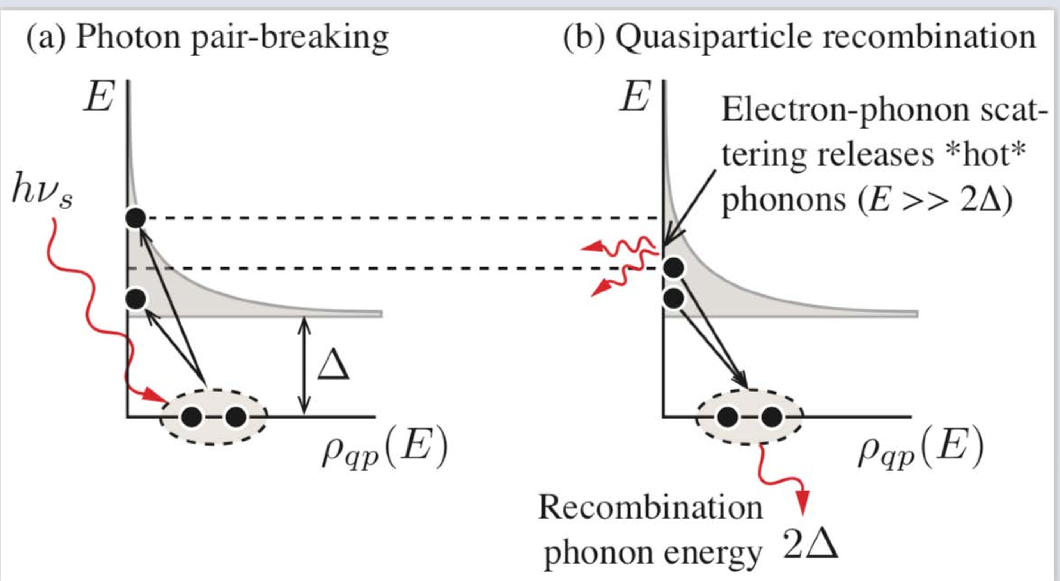
Introduction

- Kinetic inductance detectors provide several characteristics making them a compelling detector choice for astrophysical applications.
- Photon noise limited sub-mm/far-IR cold telescopes in space will require detectors with noise equivalent power (NEP) less than $1x10^{-19}$ $W/Hz^{1/2}$ for imaging applications and spectroscopic studies
- We describe the fabrication of enhanced responsivity KIDs through the incorporation of a phononic crystal choke, which suppresses the flux of recombination and athermal (hot) phonons from the superconducting film to the thermal bath.
- The phononic filters are created by etching quasi-periodic nanoscale structures into a silicon membrane which isolates the KID inductor from the thermal bath.

Design Approach



A phononic crystal matched to a superconducting resonator (or MKID) will increase the number of recombination and athermal phonons in the superconducting film. The result is increased responsivity to electromagnetic radiation.



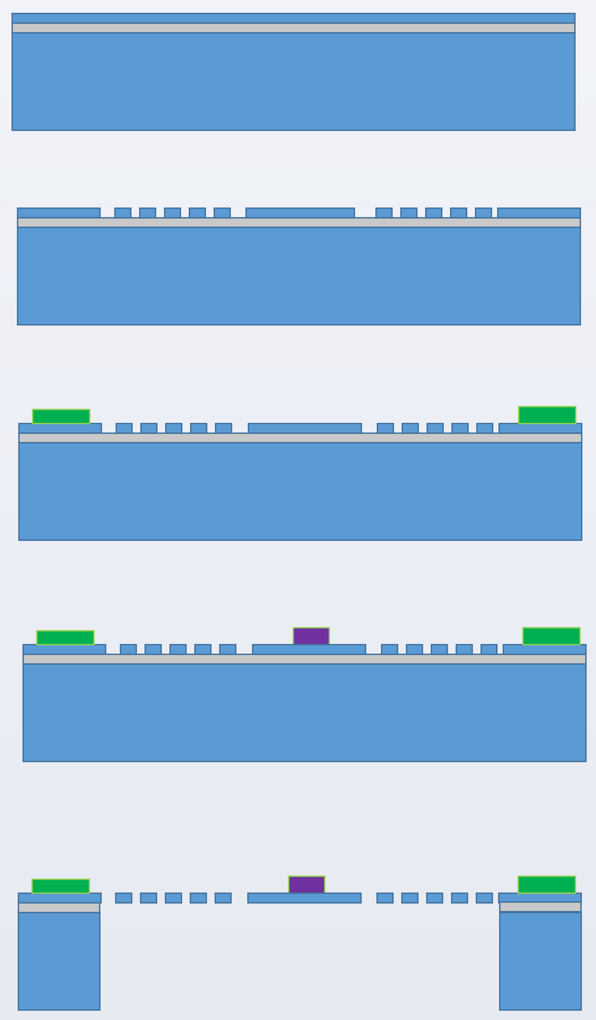
The energy resolution of state-of-the-art photon counting KIDs is nearly an order of magnitude below the statistical (Fano) limit for a pair-breaking device. We have added a meta-material phononic crystal that reduces the loss of recombination and athermal phonons from a KID. The phononic crystal

(1) increases the responsivity of the MKID to signal photons,

(2) reduces the NEP due to quasiparticle generation-recombination (GR) noise, and

(3) reduces the loss of athermal phonons to the detector substrate, directly impacting the energy-resolving power of an optical/NIR KID.

Fabrication Process



Silicon on insulator wafer with 90 nm thick device layer

Pattern phononic features using electron beam lithography. Etch into the device layer and stop on the buried oxide.

Pattern niobium CPW feed line and capacitor using laser lithography, sputter deposit and liftoff the niobium layer.

Pattern hafnium inductor using laser lithography, sputter deposit and liftoff the hafnium layer.

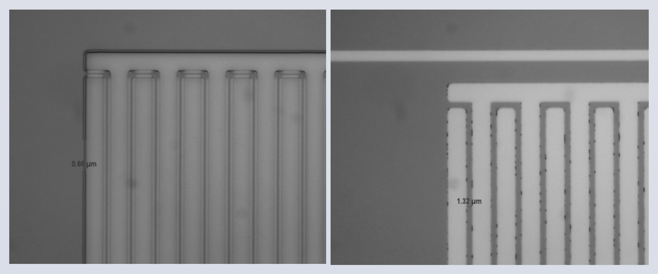
Bond wafer with wax to a handle wafer (not shown). Pattern handle wafer side of silicon wafer and deep reactive ion etch to create membrane. Remove handle wafer by dissolving wax.

Simplified fabrication scheme for TES bolometers with thermal isolation beams isolated by phononic filters

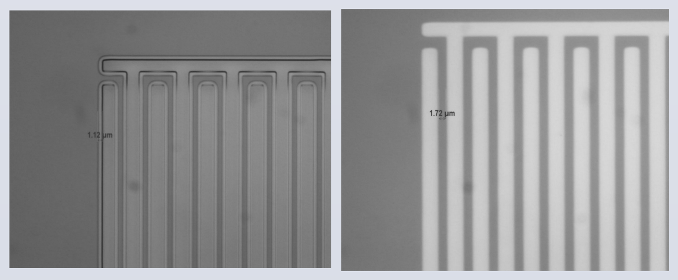
Material	Thickness [nm]	Process	
Niobium	50	DC Sputter	Liftoff PMGI S1805
Hafnium	65	DC Sputter	Liftoff PMGI,S1805
Gold heat sink / heater	300	Electron beam evaporation	Lift-off AZ-5214E in acetone
Si membrane	90	LPCVD	Etch: SF_6/CHF_3 at 100 W, 20 mT
SiO_2 etch stop	300	Thermal Oxidation	Buffered HF (7:1)
Silicon	300 (um)	Deep Reactive Ion Etch	BOSCH SF_6, C_4F_8

Material thicknesses and process information. A similar process could be achieved using SiN/SiO coated wafers

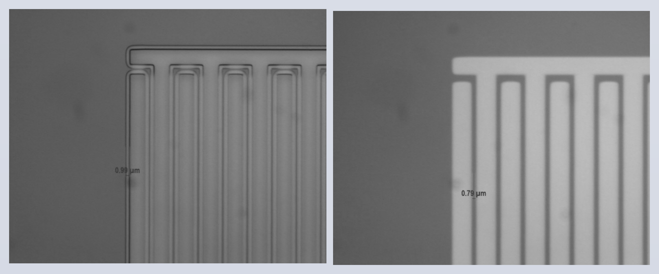
Fabrication Results – Laser lithography



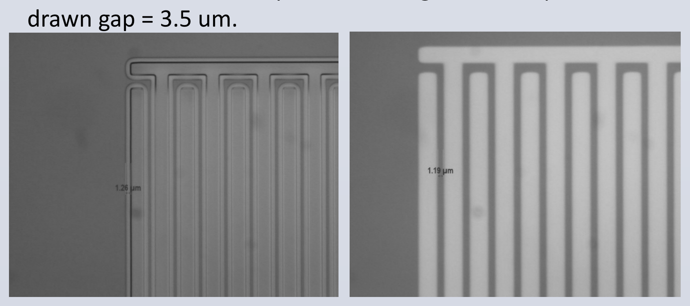
Wafer 1: ~0.65-0.7 um undercut. Undercut was insufficient and produced flags.



Wafer 5: 1 min 35 s development in MF319 resulted in ~1 – 1.15 um undercut. Pretty clean but flags in a few spots. As drawn gap = 3.5 um.



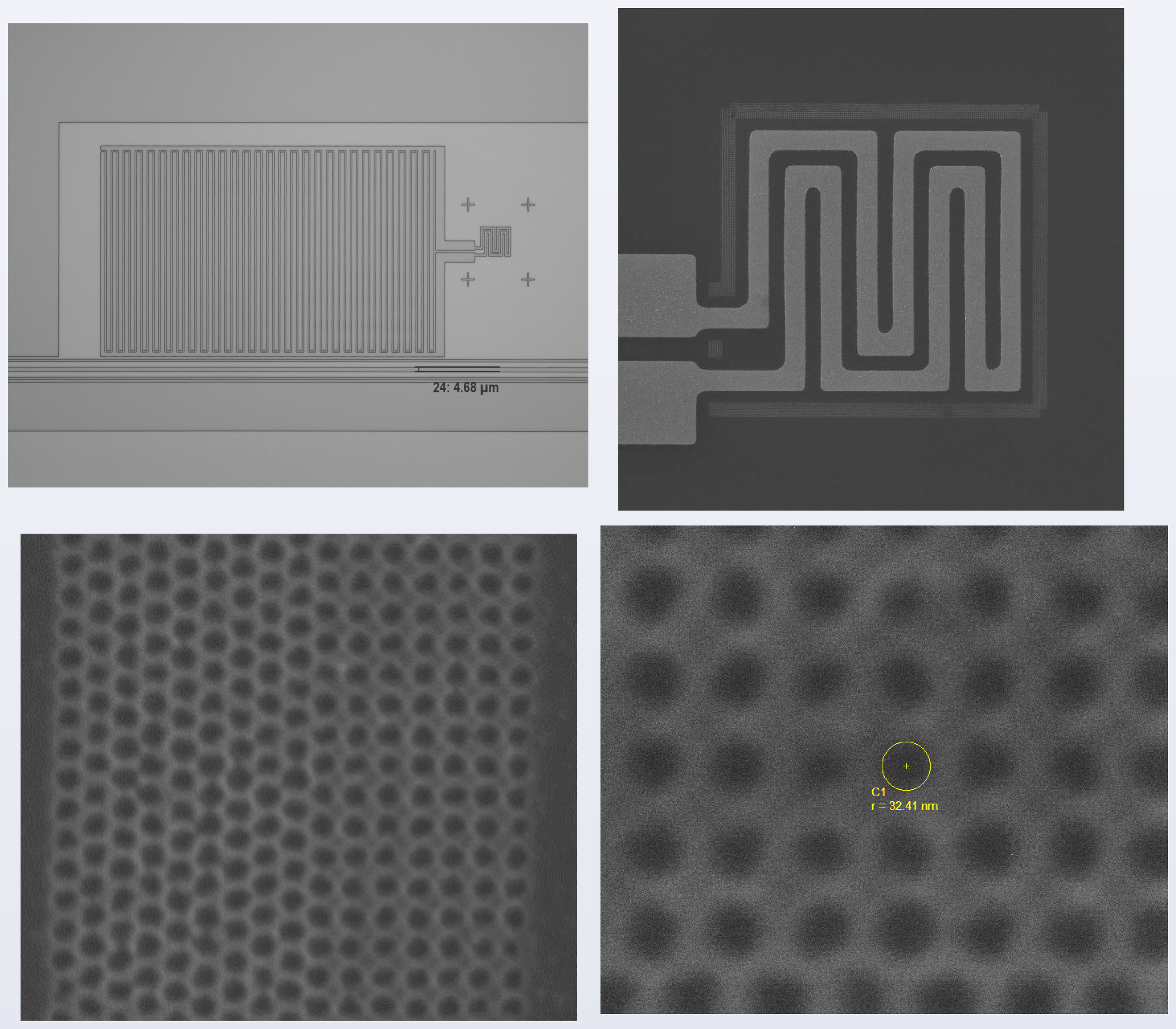
Wafer 2: 1 min 40 s development in MF319 resulted in ~1 – 1.15 um undercut. Pretty clean but flags in a few spots. Delamination occurring b/c 2.5um gap too small to support resist.



Wafer 4: 1 min 50 s development in MF319 resulted in ~1.26 um undercut. No flags observed. Initial 3um gap between lines results in close to 1 um as fabricated gap.

A bilayer of LOR-5A/S1805 resist is used for laser lithography exposed in a Heidelburg DWL 66+ using the high resolution write head with minimum features sizes of 0.4 um. It is found that to avoid "flags" a minimum of 1.25 um undercut is required. To achieve a 1 um gap between lines, an as drawn gap of 3 um is required which leaves 0.5 um of resist for structural support after the 2.5 um undercut.

Fabrication Results Electron Beam lithography



SEM micrographs of etched silicon phononic structures. The silicon is patterned using ZEP 520 resist spun at 2.5krpm, in a Zeiss 100kV with 500uC/cm² dose. The features are designed as 60 nm diameter circles and exposed as polygons rather than as zero dimensional spots to give approx 64 nm diameter as fabricated holes on a 110 nm pitch. Phononic pattern consists of both hexagonal and square tiling.

Conclusions

- A fabrication process mixing direct write laser, contact, and electron beam lithography was developed to integrate a phononic filter into a KID geometry.
- We have developed a new liftoff process using direct write laser based lithography enabling 1 um spaces in sputtered Nb and Hf films.
- Electron beam lithography and etching with minimum features of 50 nm has been demonstrated.
- The new process incorporates a Nb microwave feedlines with a Hf inductor deposited by a DC sputtering process with Tc of 430 mK, Ls = 28pH/sq. Internal quality factor greater than 10^5 has been measured.

References

[1] "Enhanced Quasiparticle Lifetime in a Superconductor by Selective Blocking of Recombination Phonons with a Phononic Crystal", K. Rostem, P.J. de Visser, E.J. Wollack, Physical Review B, 98 014522 (2018)

[2] . "Superconducting microresonators: Physics and applications.", J. Zmuidzinas, Annu. Rev. Condens. Matter Phys., 3(1):169-214, 2012.

[3] "Counting near infrared photons with microwave kinetic inductance detectors." W. Guo, X. Liu, Y. Wang, Q. Wei, L. F. Wei, J. Hubmayr, J. Fowler, J. Ullom, L. Vale, M. R. Vissers, and J. Gao. Applied Physics Letters, 110(21):212601, 2017.

[4] "Generation-recombination noise: The fundamental sensitivity limit for kinetic inductance detectors." P. J. de Visser, J. J. A. Baselmans, P. Diener, S. J. C. Yates, A. Endo, and T. M. Klapwijk. Journal of Low Temperature Physics, 167(3):335-340, May 2012.

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