Fabrication of an antenna-coupled KID array for CMB detection

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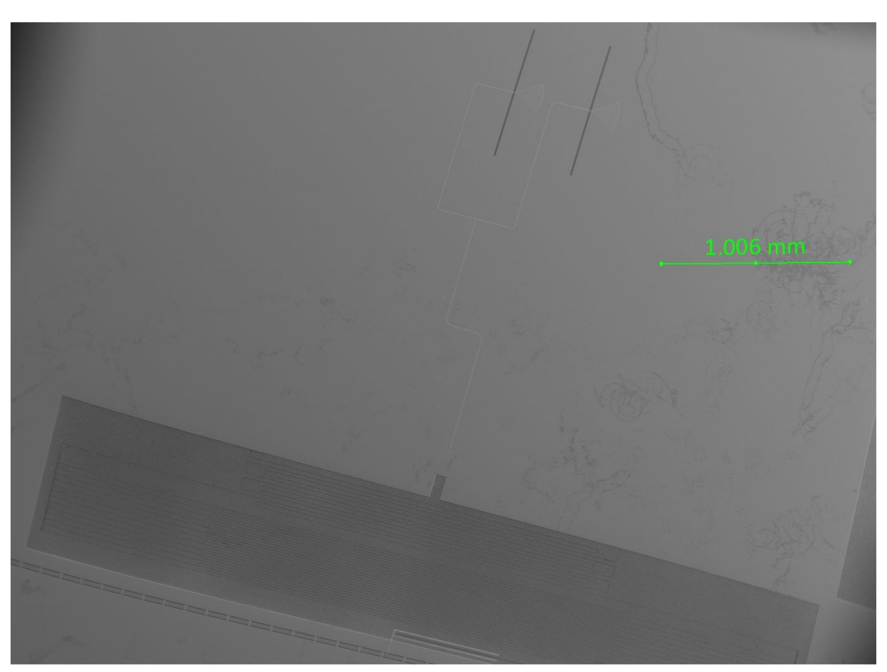
Introduction

Superconducting technology has become ubiquitous as detectors in sub-mm cosmological experiments. One of the ongoing challenges is to fit as many detectors as possible while having a simple readout system. Microwave Kinetic Inductance Detectors (MKIDs) are an attractive alterative to traditional superconducting detectors due to their high multiplexing capabilities and simple fabrication processing, which are extremely beneficial for large arrays of detectors. Our goal is to utilize KIDs for the next generation Cosmic Microwave Background (CMB) experiment, CMB-Stage 4, which plans to deploy 500,000 detectors in order to measure primordial gravitational waves from inflation, the sum of neutrino masses, and many other science goals [1]. We designed and fabricated an antenna-coupled KID array optimized for CMB studies. Our design uses a twin slot antenna coupled to inverted microstrip made from superconducting Nb and silicon nitride (SiN) coupled to an Al KID grown on high resistivity Si. For details, please refer to E. Shirokoff poster (PA-13).



Scanning electron microscope image of an KID with antenna slots.

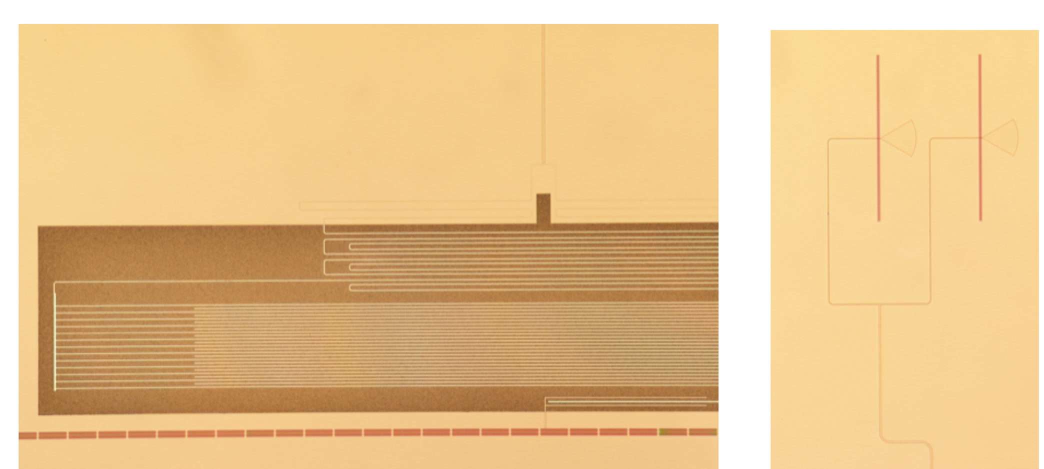
Step	Layer	Photoresist	Laser (nm)	Dosage (mJ/cm^2)
2,8	Nb CPW/ground plane	AZ 1512	375	100
3	Al KIDs	AZ 1512	375	130
6	Si Holes/Lenses	AZ 1518	405	135
9	Si_3N_4	AZ 1512	375	110
	SU-8 posts	SU-8 3050	375	245

Lithography details for fabrication of the detector wafer and lens seating wafer. Step number matches the process step shown in the cross-sectional view of wafer processing (right). All lithography steps are done using the Heidelberg MLA150 machine.

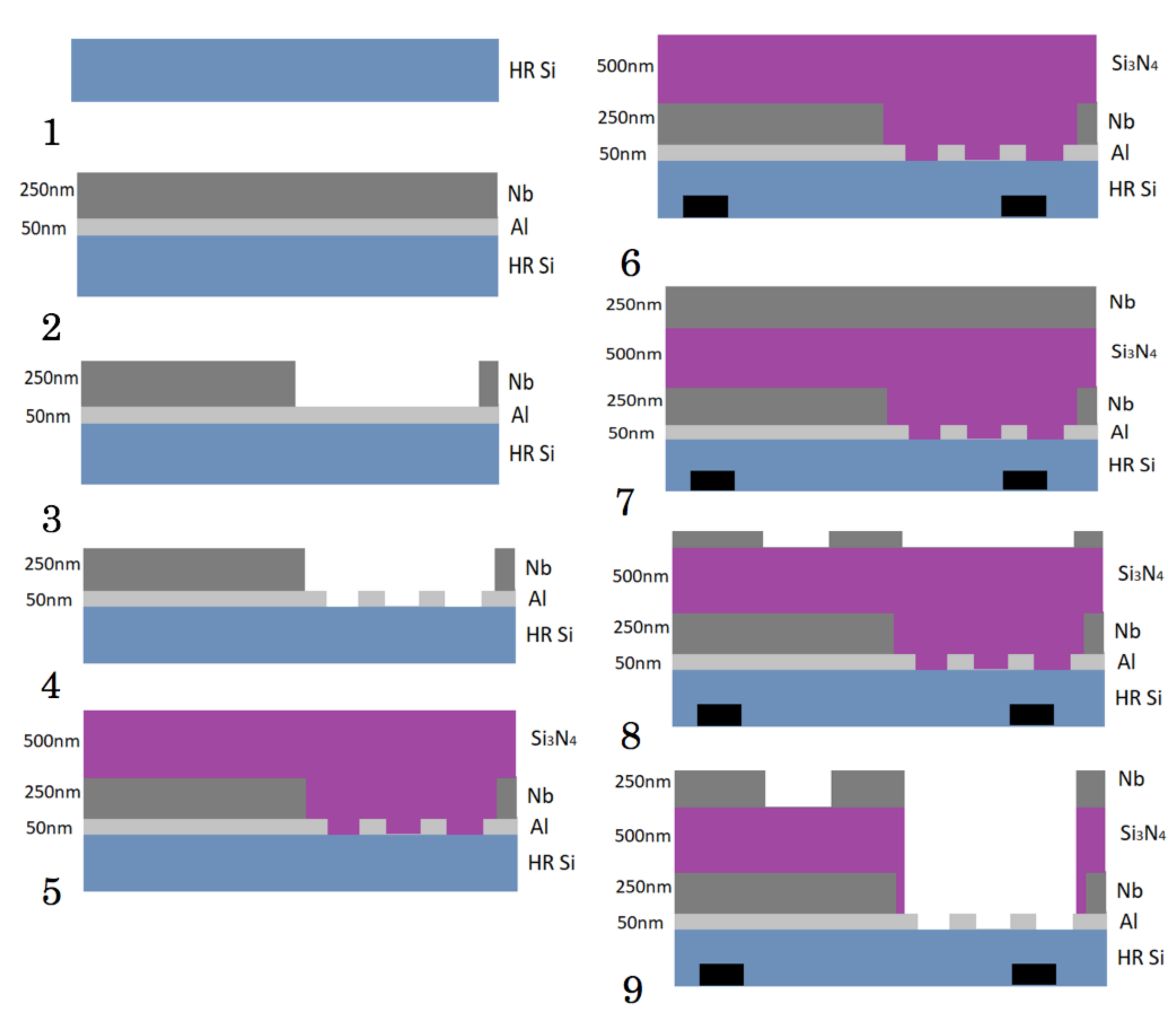
Fabrication Steps

All the fabrication was done in the Pritzker Nanofabrication Facilities at University of Chicago.

1. A hydrofluoric acid dip and vacuum bake at 150ºC on a double-sided polished high resistivity (HR) Si wafer for cleaning.
2. Deposit 50nm of Al and 250nm of Nb in vacuum using e-beam.
3. Pattern the Nb layer. Etch the Nb layer using inductively coupled plasma (ICP) Fl etcher to form the microstrip lines.
4. Pattern the Al layer. Wet etch the Al layer using Aluminum Etchant Type A to form the KID layer.
5. Grow 500nm of SiN using high density plasma chemical vapour deposition to form the dielectric layer of the microstrip.
6. Deep silicon etch 80um into the backside of wafer for lens wafer alignment holes.
7. Deposit 250nm of Nb to form the ground plane using e-beam.
8. Pattern and etch the top Nb layer using ICP Fl etcher to form the antenna slots.
9. Pattern and etch the SiN layer using ICP Fl etcher to open up the Al KIDs.



Optical microscope images of the KID (left) and antenna slots (right).

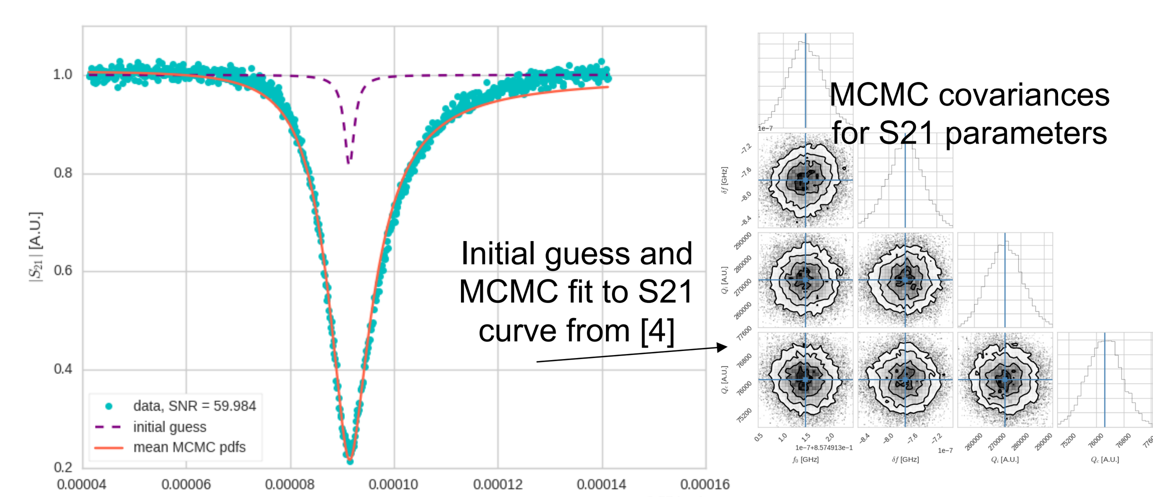


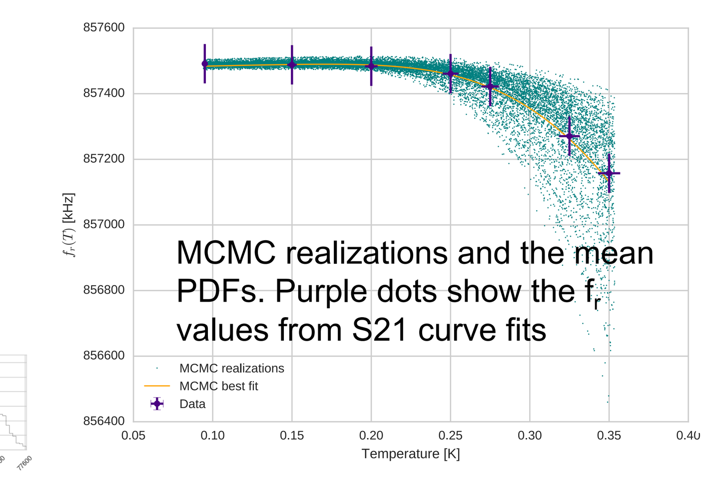
Cross-sectional view of wafer during fabrication processing.

RESULTS

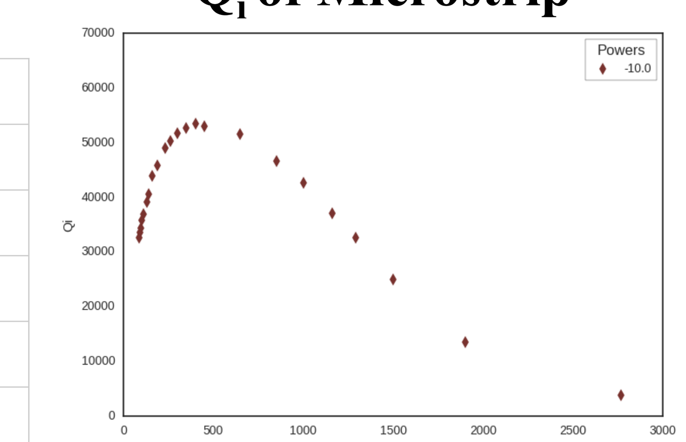
The dark testing was done in an Adiabatic Demagnetization Refrigerator (ADR). From each S21 sweep, we fit to our data and retrieve the parameters: resonance frequency f_r, asymmetry parameter δf, and quality factors Q_i and Q_c. Frequency data sweeps are done at many temperatures to understand the full temperature dependency of our parameters. We fit our data using Markov Chain Monte Carlo (MCMC) methods with emcee[2] package, using formalism from Gao [3].

S21 Analysis





Q_i of Microstrip

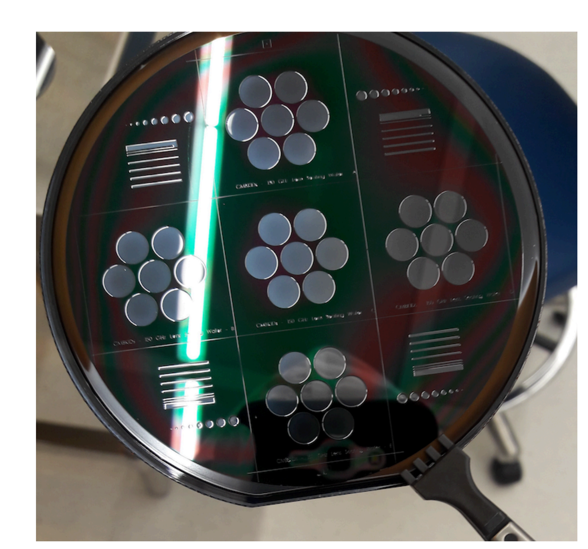


We fabricated and tested microstrip resonators with the same dimensions to test the loss of the microstrip transmission line.

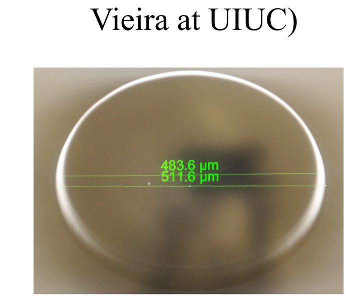
Lens Wafer Alignment

We use 1/4-inch diameter alumina lenslets to couple light to the detectors. The lenslets are provided and applied by the Vieira group at University of Illinois Urbana-Champagne.
The lenslets are glued onto the lens seating wafer, made from a 500um thick double-sided polished silicon substrate. We pattern the lenslet holes, and subsequently deep silicon etch 250um into the wafer.
To align the lens wafer and the detector wafer, we pattern posts made from SU-8 3050, a permanent epoxy negative photoresist, on the backside of the lens seating wafer. Each post is approximately 70um tall and 500um wide in diameter, designed to fit the 80um deep holes on the backside of the detector wafer.

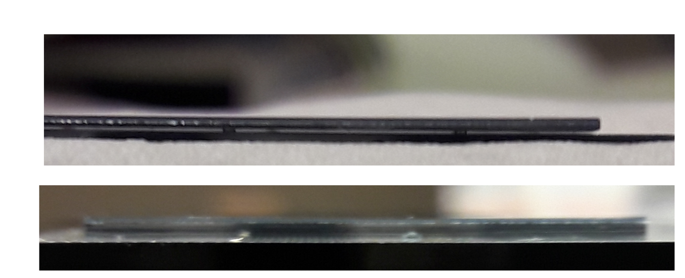
Photograph of a partially populated seating wafer chip with alumina lenslets (lenses are provided by J. Vieira at UIUC)



Front view of the lens seating wafer



Scanning electron microscope image of the SU-8 posts.



Side view of the lens wafer when the posts are misaligned with the holes (top) and aligned (bottom).

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Conclusion

We have fabricated a lens seating wafer and a prototype antenna-coupled KID array, achieving Q_i ~300,000. We designed a new lens wafer alignment procedure using SU-8 posts. In addition, we have demonstrated a low-loss SiN microstrip. We plan to follow up with optical and noise measurements shortly.

Acknowledgements

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