Preparation and $T_c$ Control of Reactively Sputtered Sub-stoichiometric TiN$_x$ Thin Films for Microwave Kinetic Inductance Detectors

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**Microwave Kinetic Inductance Detectors (MKIDs):**

- photon breaks cooper pairs, increases kinetic inductance
- superconductor part of LC circuit $\rightarrow$ change in total inductance shifts resonance frequency and resonance phase $\rightarrow$ signal
- gives photon arrival time ($\mu$S accuracy) and photon energy
- frequency domain multiplexing: many MKIDs with different $f$, can be measured using one pair of contacts

**TiN$_x$ general properties:**

- very hard conductive ceramic
- stable at room temperature over a wide range of Ti:N ratio $\rightarrow$ sub-stoichiometric deposition possible
- superconductor with $T_c$ around 5 K (Ti: $T_c$ = 0.4 K)
- high kinetic inductance $L = \frac{\mu_0 \lambda^2}{t}$
- $\lambda$: penetration depth: Al: 50 nm Nb: 75 nm TiN: 1 $\mu$m

**TiN$_x$ preparation:**

- DC sputtering of a high purity Ti target in Ar / N$_2$ mixture
- varying Ar:N$_2$ ratio allows to control the Ti:N ratio
- we use a dedicated UHV system ($p_{\text{base}} = 2 \times 10^{-10}$ Torr) to get high quality films
- optimized sputter conditions: $p = 7$ mTorr
  - 1.65 sccm Ar + 15.72 sccm N$_2$ $\rightarrow$ gives about 11 Å/S
- high impact energy of sputtered Ti atoms on the substrate necessary for high quality films
- to structure TiN: ICP etching: SF$_6$: etch rate too low
- Cl$_2$: etch rate too non-uniform for thicker films
- BC$_3$ + Cl$_2$ (2:1) works best but still uniformity issues

**Stoichiometric TiN:**

- point of stoichiometry can be determined by minimum in room temperature sheet resistivity
- Ti:N ratio dependent on N$_2$ flow rate
- LC circuit low power Q$_i$ up to $3 \times 10^6$, dependent on film stress
- film stress can be optimized by varying the sputter pressure

**Sub-stoichiometric TiN$_x$:**

- when sputtered at 7 mTorr, stress shows no substantial dependence on Ar flow
- variation in $x$ allows control of $T_c$
- we aim for a $T_c$ between 0.8 K and 1.0 K

- $T_c$ shows a sharp transition $\rightarrow$ careful control of all sputter parameters necessary
- reproducibility is good, visible data scatter mainly caused by lateral variations
- main challenge of TiN$_x$: film uniformity. At the moment we see a huge variation of $T_c$ over a 4” wafer. We expect to reduce that by further optimized deposition conditions.
- we achieve low power Q$_i$ of up to $5 \times 10^5$

**first results:**

- we use TiN$_x$ in optical and in x-ray MKIDs
- optical MKIDs will be presented in a talk by Ben Mazin on Tuesday
- first results on x-ray MKIDs will be shown on Wednesday by Gerhard Ulbricht

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This work was supported by NASA grants NNX10AF58G and NNX13AH34G