Microwave Kinetic Inductance Detectors for Synchrotron Hard X-ray Science

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Overview

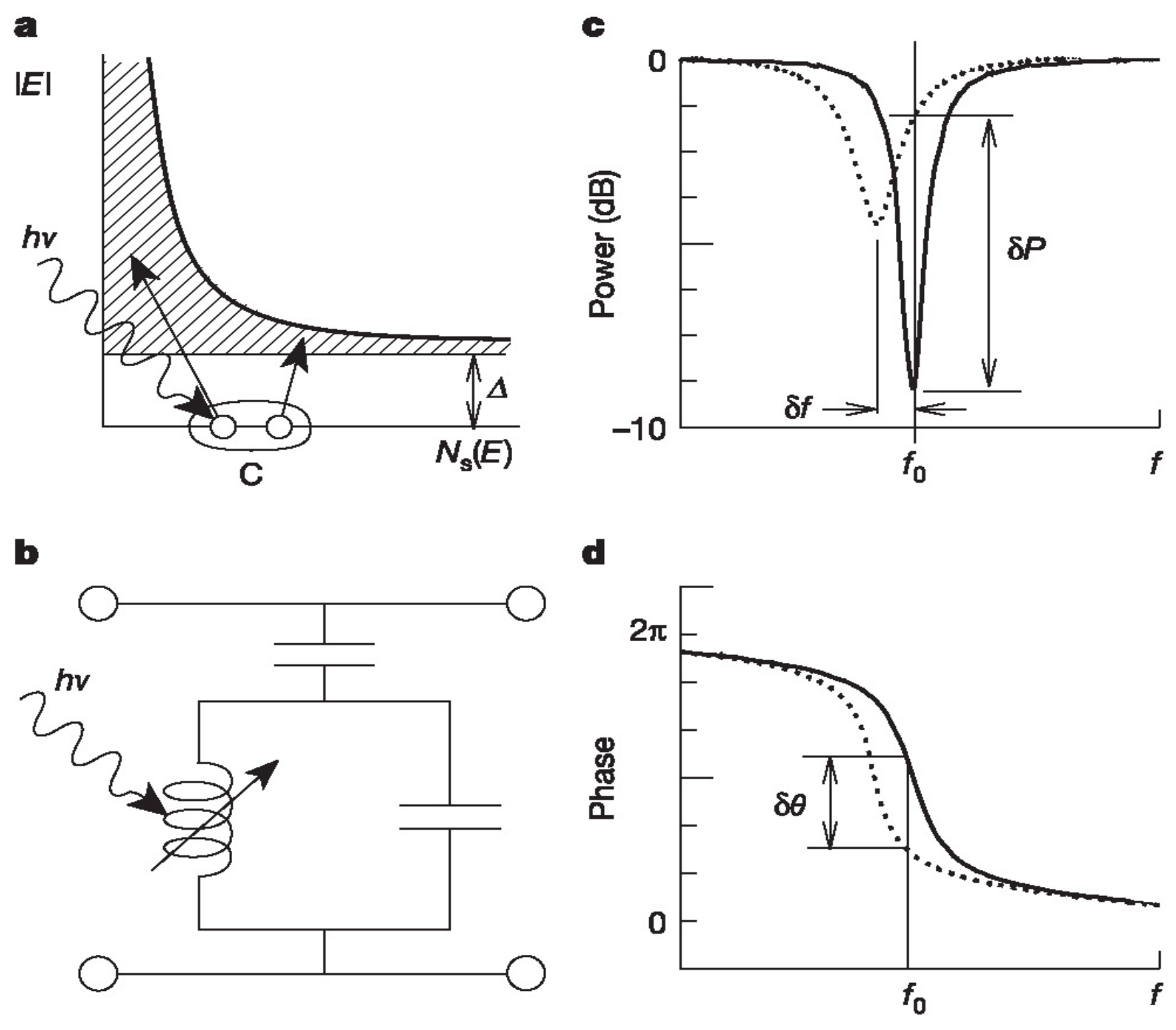
The lack of efficient X-ray detectors is often the main factor limiting the effective use of ever more powerful synchrotron light sources. We describe a detector research and development program to develop the next-generation of high-resolution spectroscopic x-ray detectors using superconducting Microwave Kinetic Inductance Detectors (MKIDs). We discuss detector requirements specific to hard X-ray synchrotron applications and provide a comparison of the capabilities of coplanar waveguide MKIDs using quasiparticle trapping and Lumped Element MKIDs. Additionally, initial results of investigations of resonator and absorber materials will be presented.

MKID Concept & Detector Requirements

The Advanced Photon Source (APS) is a hard X-ray synchrotron with an energy range that can be tuned from 1-120 keV with monochromatic direct beam fluxes ranging from 10^{10}-10^{12} photons/s. Synchrotron x-ray spectroscopic experiments study biological, geological, and solid-state samples. The use of intense synchrotron beams allows one to detect trace amounts of elements. Depending on the specific experiment and sample under study, each of these experiments has different priorities in terms of detector specifications. However, they share some common requirements. **The four main detector requirements are: solid angle coverage, count rate, peak to background ratio, and energy resolution.**

MKID Operation

Superconducting kinetic inductance detectors detect the change in quasi-particle density due to an absorbed photon through the change in kinetic inductance. The change in kinetic inductance can be read out by forming the superconductor into a high Q resonator



(a) Photons break Cooper pairs in a superconductor, creating quasiparticles.

(b) Quasiparticles change the inductance of a resonant circuit.

(c) The resonance shifts to lower frequency and becomes broader and shallower.

(d) The density of quasiparticles, which reflects the absorbed energy, can be monitored by measuring the shift in phase of a microwave signal sent through the resonator.

Four Main Detector Requirements

•**Solid Angle Coverage**: Most applications rely on detection of weak signals (i.e. fluorescence photons). To limit collection time, the largest solid angle possible is desired.

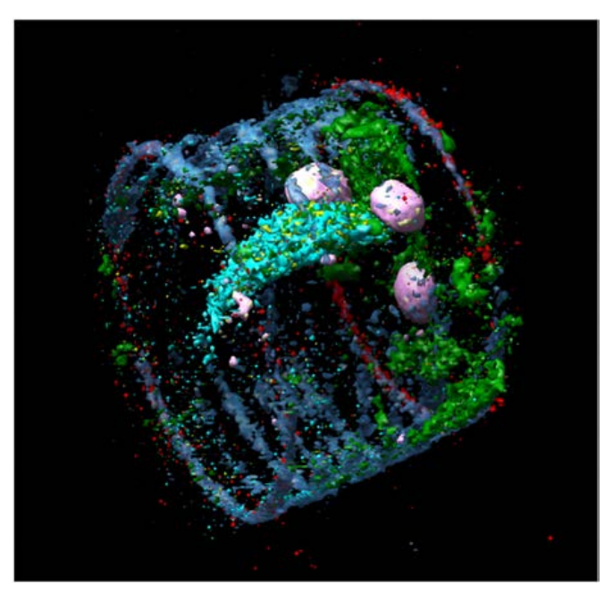
•**Count Rate**: Maximum count rate is determined by the response time of the detector. The total count rate can be increased by using arrays of detector pixels.

•**Peak to Background Ratio**: Intense synchrotron beams produce large amounts of scattered photons. These photons create an asymmetric background (seen as a long, low energy tail) due to incomplete charge collection. A high background increases collection time to detect weak signals.

•**Energy Resolution:** Increased energy resolution allows differentiation of overlapping fluorescence lines

Potential Applications

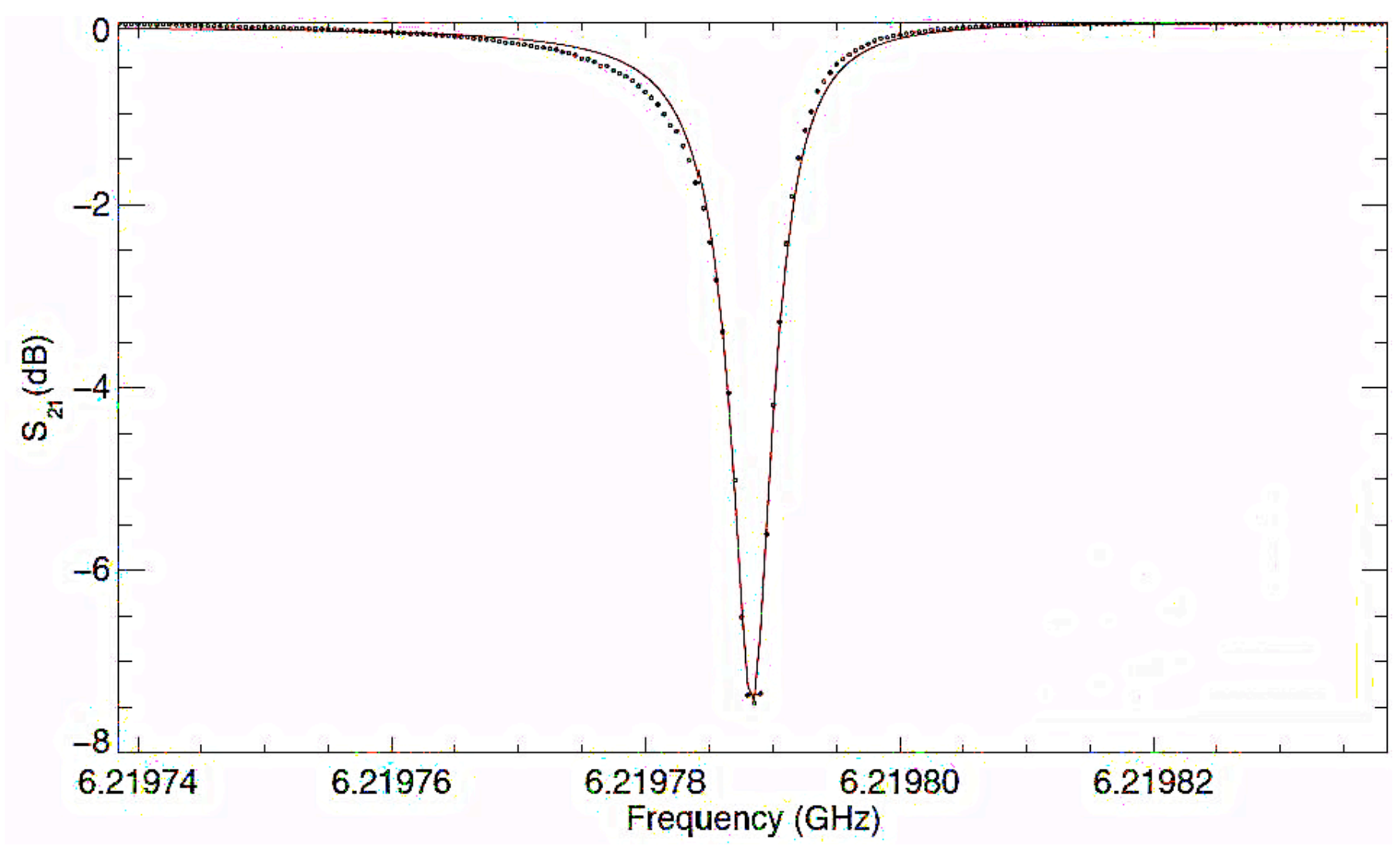
- X-ray Fluorescence Microscopy
- X-ray Fluorescence Tomography
- X-ray Absorption Spectroscopy
- X-ray Powder Diffraction
- Energy Dispersive X-ray Diffraction



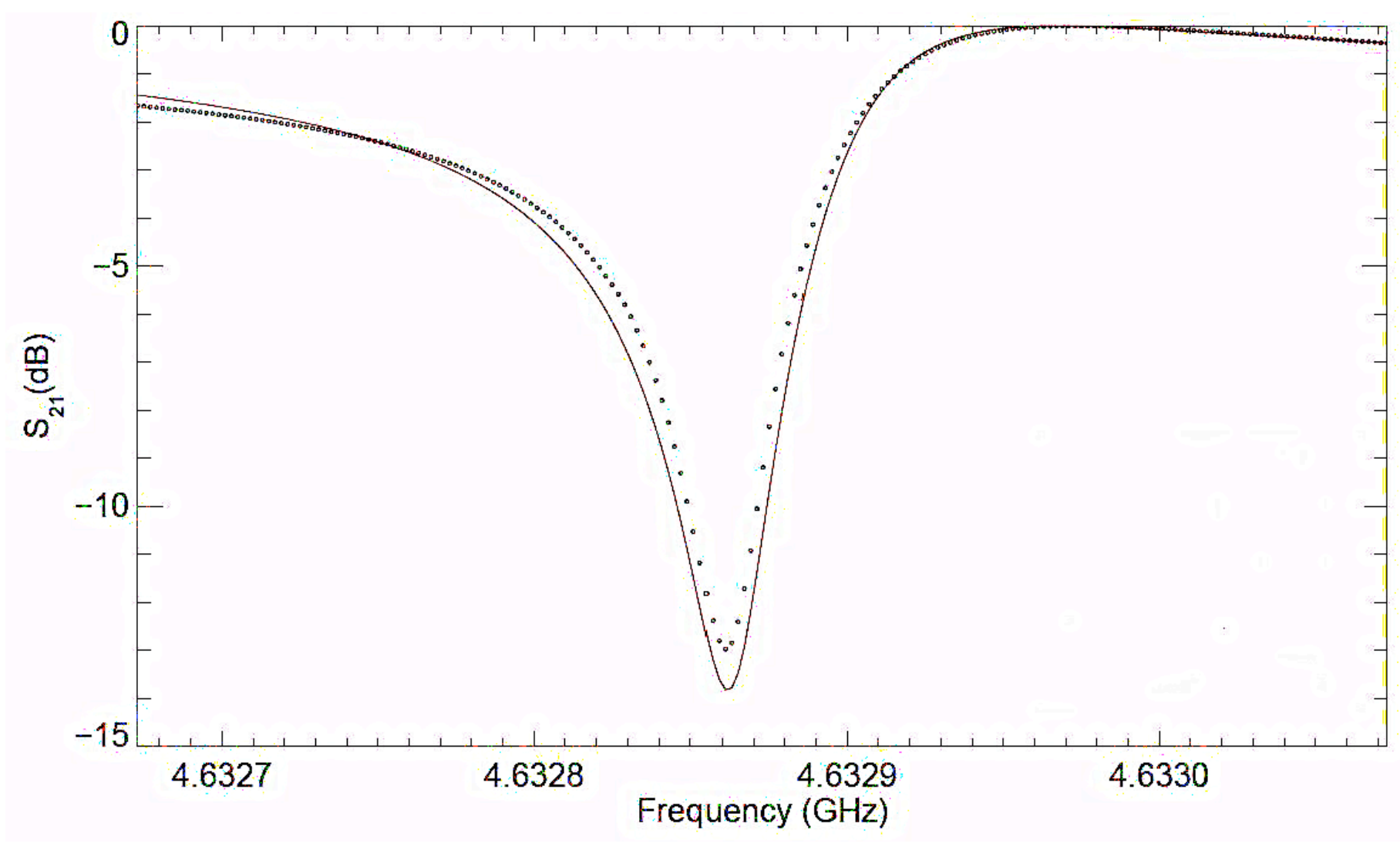
3D distributions of the elements (Si, P, S, Cl, K, Ca, Mn, Fe, Cu, and Zn) in the freshwater diatom *Cyclotella meneghiniana* (de Jonge, et al 2010)

Results and Future Work

Resonator Fabrication

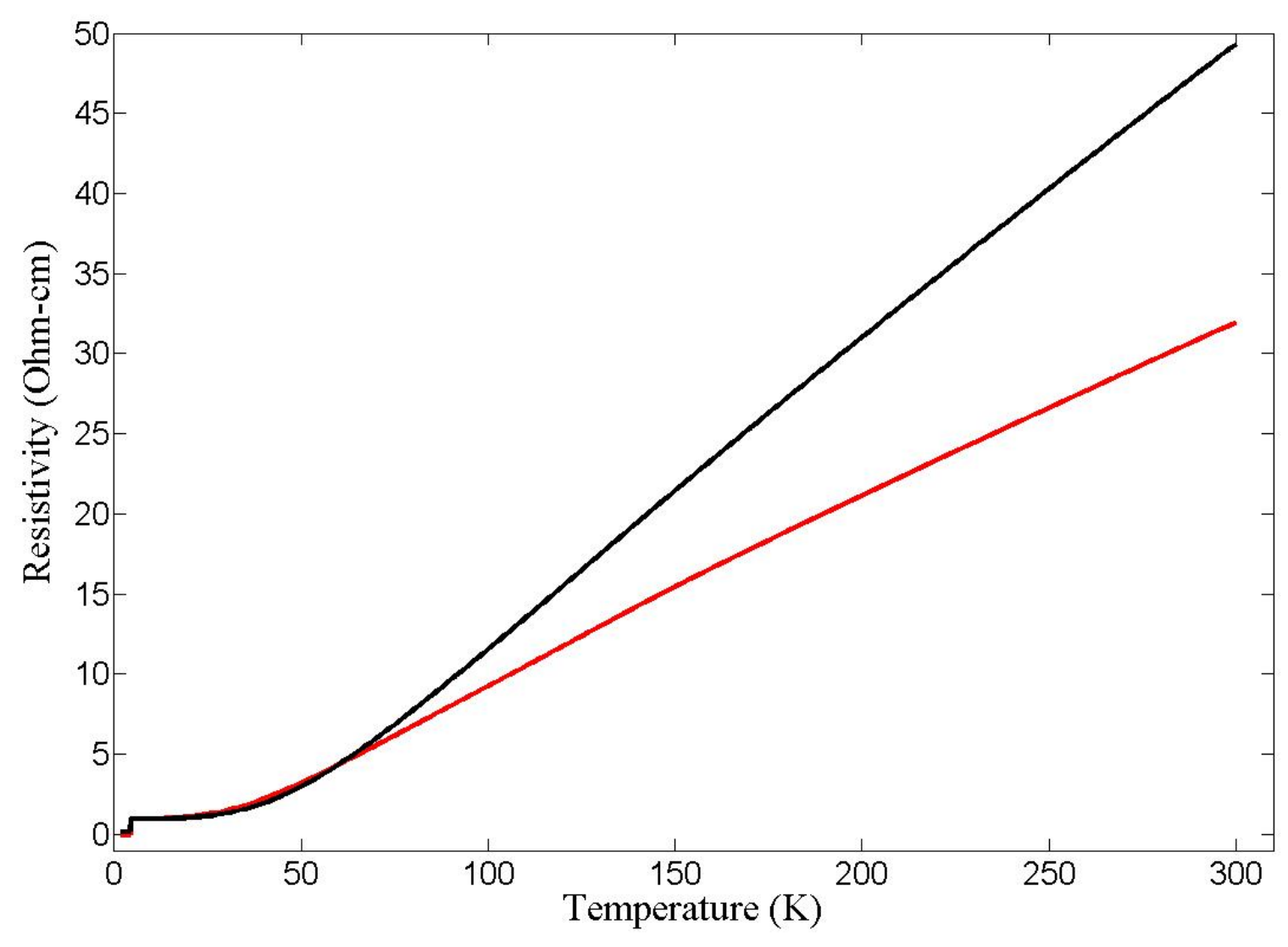


300nm Al CPW Resonators with internal Q of 2.39×10^6



300nm W_5Si_3 CPW Resonator with internal Q of 2.56×10^5

Absorber Fabrication



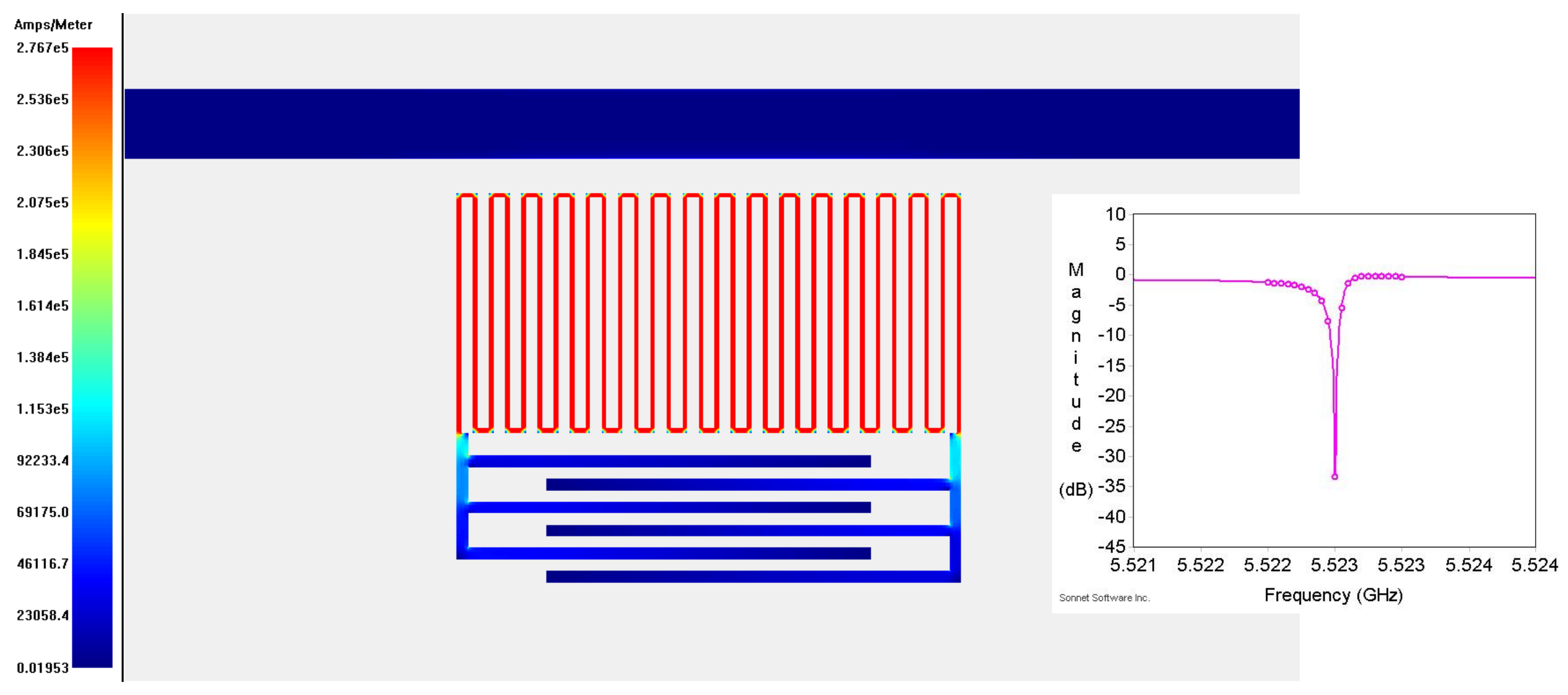
Normalized resistivity as a function of temperature for Ta films deposited at 800°C on R-plane sapphire

Tantalum Absorbers
  - Attenuation length of 1.79um at 6keV
  - Theoretical energy resolution of 2.79eV at 6keV
  - Epitaxial growth

Optimizing Deposition Conditions
  - R-plane sapphire @ 800°C
  - Tc ~ 4.3K
  - 100nm film (red line) ➔ RRR of 32
  - 500nm film (black line) ➔ RRR of 49

Lumped Element Simulation

- EM simulations using SONNET
- Simulations account for surface impedance
- We are developing models for “thick” films (500nm to 5um)



SONNET simulation of current density in a pixel with 100um long, 2um wide inductor lines with 5um spacing. Insert: Resonance dip at 5.523GHz.

Next Steps

- Investigate resonator/absorber interface quality
- Modeling of thicker absorbers (>1um)
- Fabricate single resonator lumped element devices

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