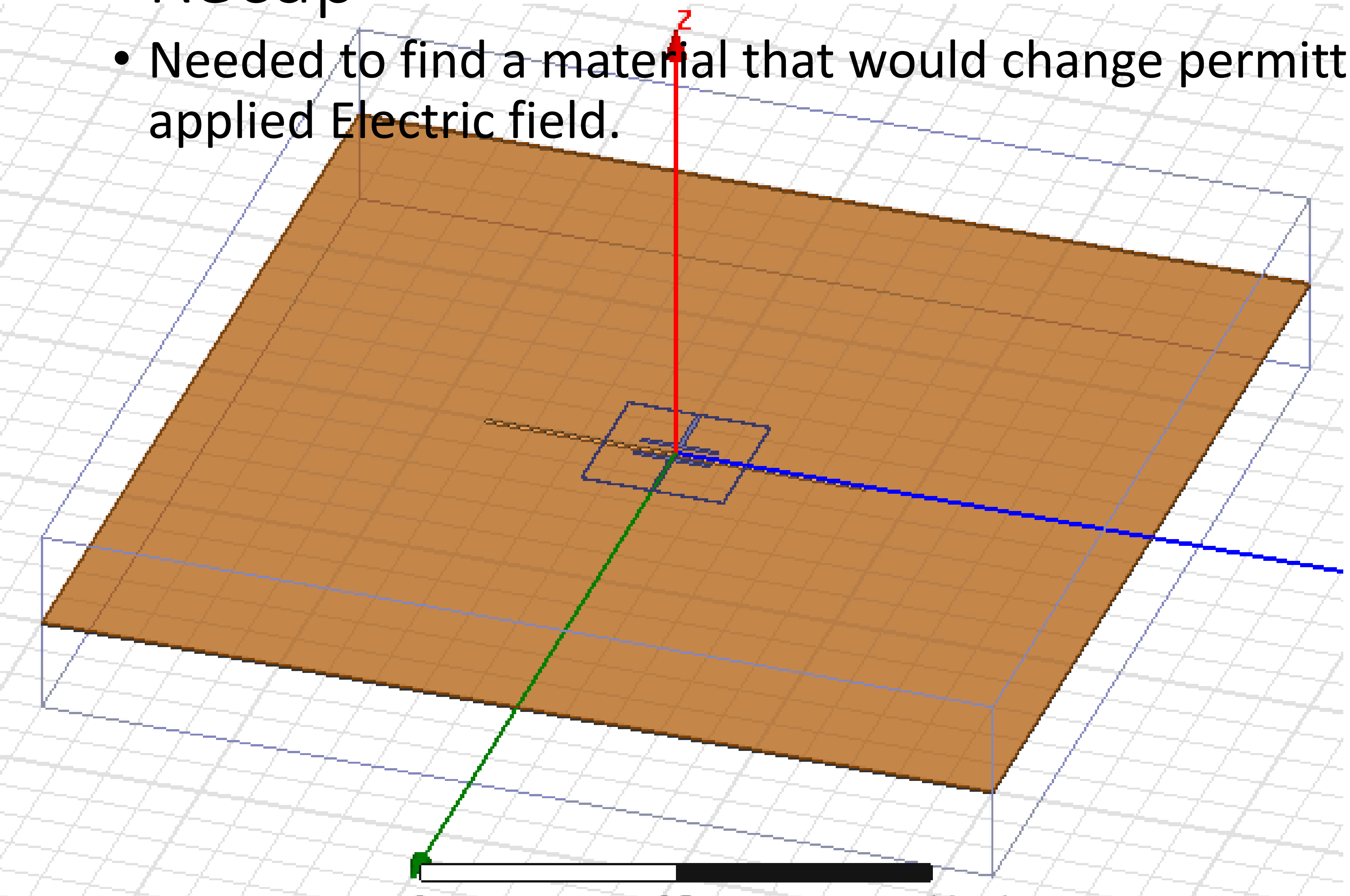
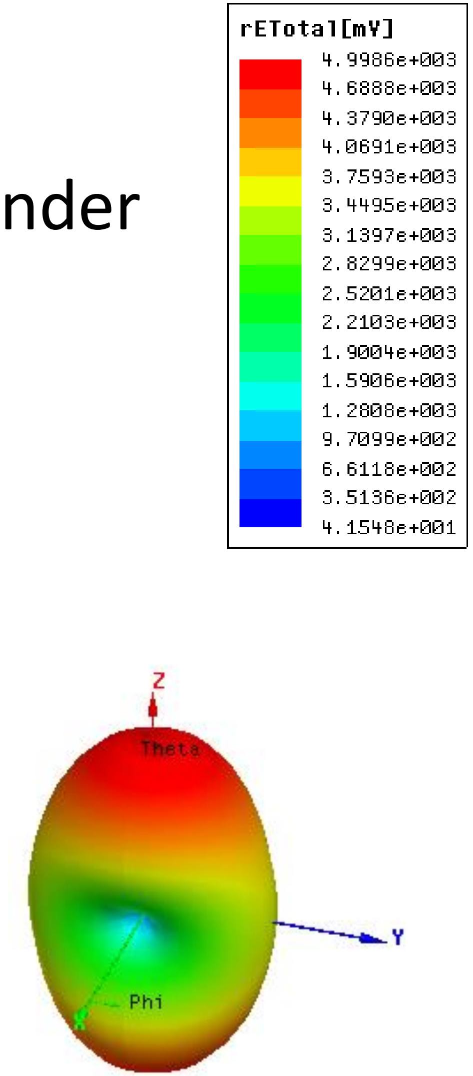
Strontium titanate – summary for use in antenna arrays

Feb 28th 2017 - Corwin

Recap

- Needed to find a material that would change permittivity under applied Electric field.

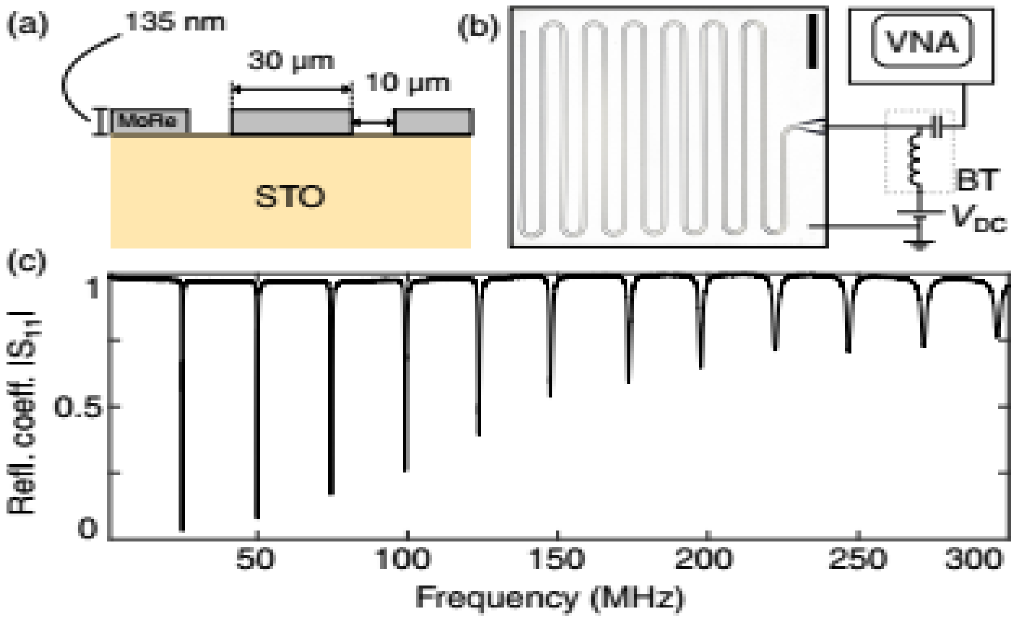


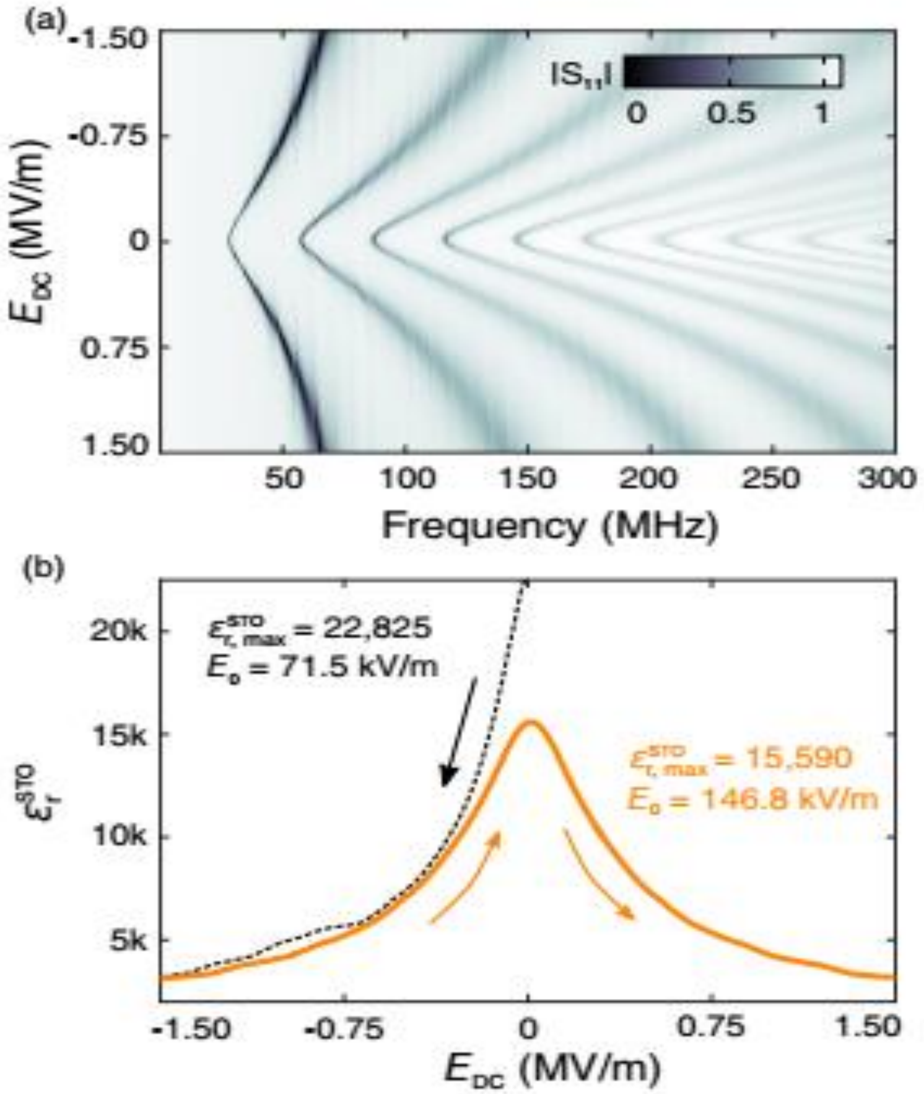


Quantum paraelectricity probed by superconducting resonators

D. Davidovikj[‡,*] N. Manca[‡,†] H. S. J. van der Zant, A. D. Caviglia, and G. A. Steele

(Dated: July 28, 2016)





Molecular Beam Epitaxy of $SrTiO_3$ Films on Si(100)-2×1 with SrO Buffer Layer

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(Received December 17, 1997; accepted for publication May 18, 1998)

1. Strip away SiO2 layer on Si Substrate
2. Grow SrO
   - Evaporate Sr metal in O2 atmosphere (5*10^(-8) torr @ 300-700C)
3. Grow SrTiO3
   - Evaporate Sr using effusion cell and Ti using electron gun in O2 atmosphere at 4*10^(-9) Torr @ 500-700C

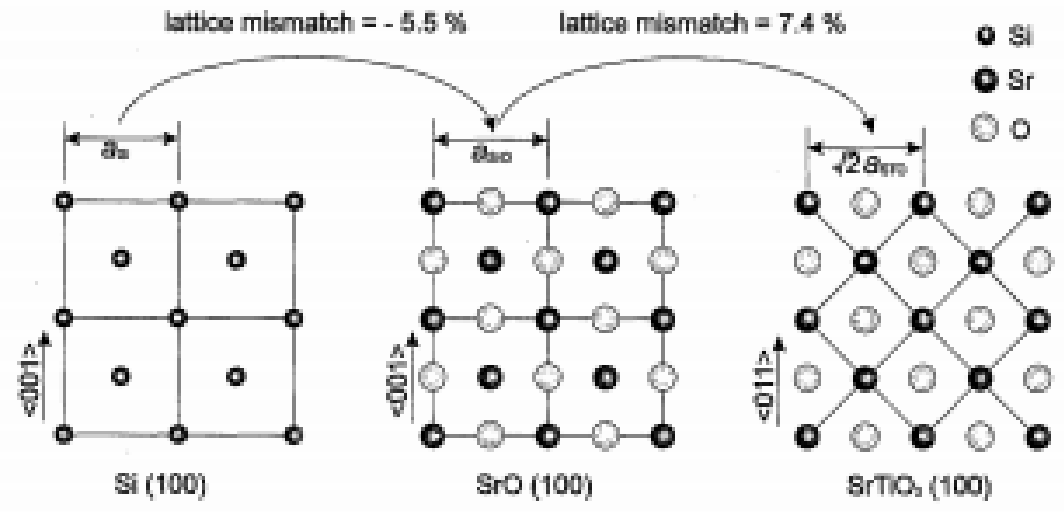
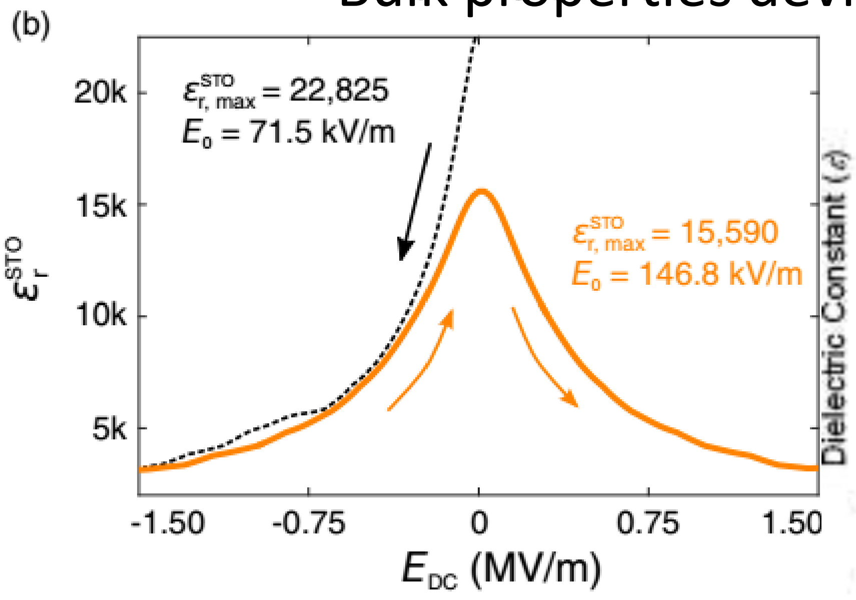


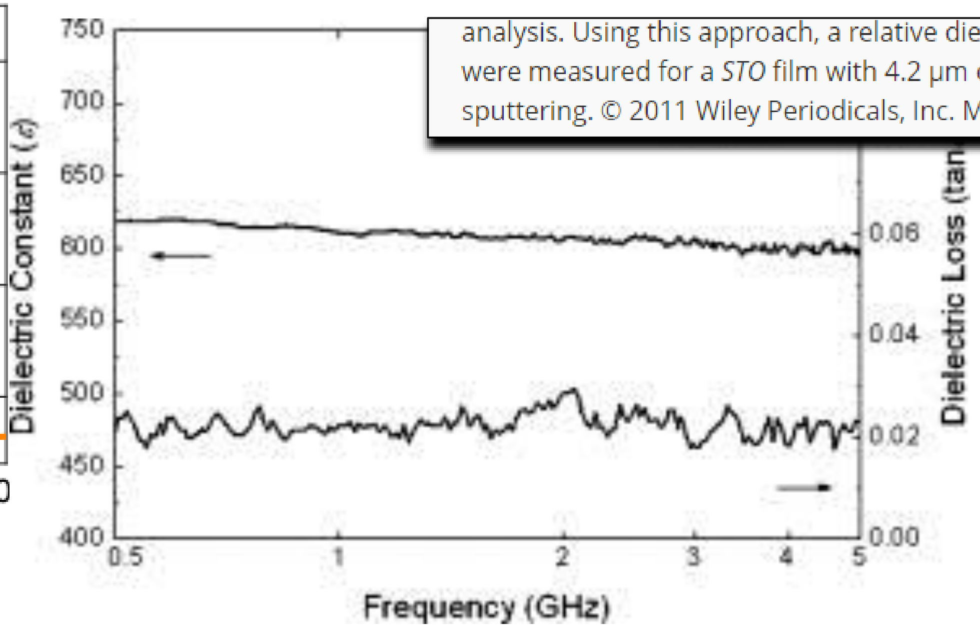
Fig. 9. Atomic configurations and lattice mismatches.

Substrate Stack

What’s a reasonable dielectric constant?

- No paper deals with our constraints of low temperature (<4K) AND high frequency (150GHz) AND Thin Film (<1um).
  - STO undergoes phase transition at 4K
  - Bulk properties deviate from thin film properties due to crystal domains?





analysis. Using this approach, a relative dielectric constant of 95 and a loss tangent less than 10^{-3} were measured for a *STO* film with 4.2 μm of thickness deposited by radio frequency (RF) magnetron sputtering. © 2011 Wiley Periodicals, Inc. Microwave Opt Technol Lett 53:2418–2422, 2011; View this

Low Temperature (<4 K)**

Thick film (500um)

Low Frequency (50MHz)

Quantum Paraelectricity probed by superconducting resonators

Room temperature

Thin Film (350nm)

High Frequency

Microwave dielectric relaxation of polycrystalline (Ba, Sr) TiO3 Thin Films

Room temperature

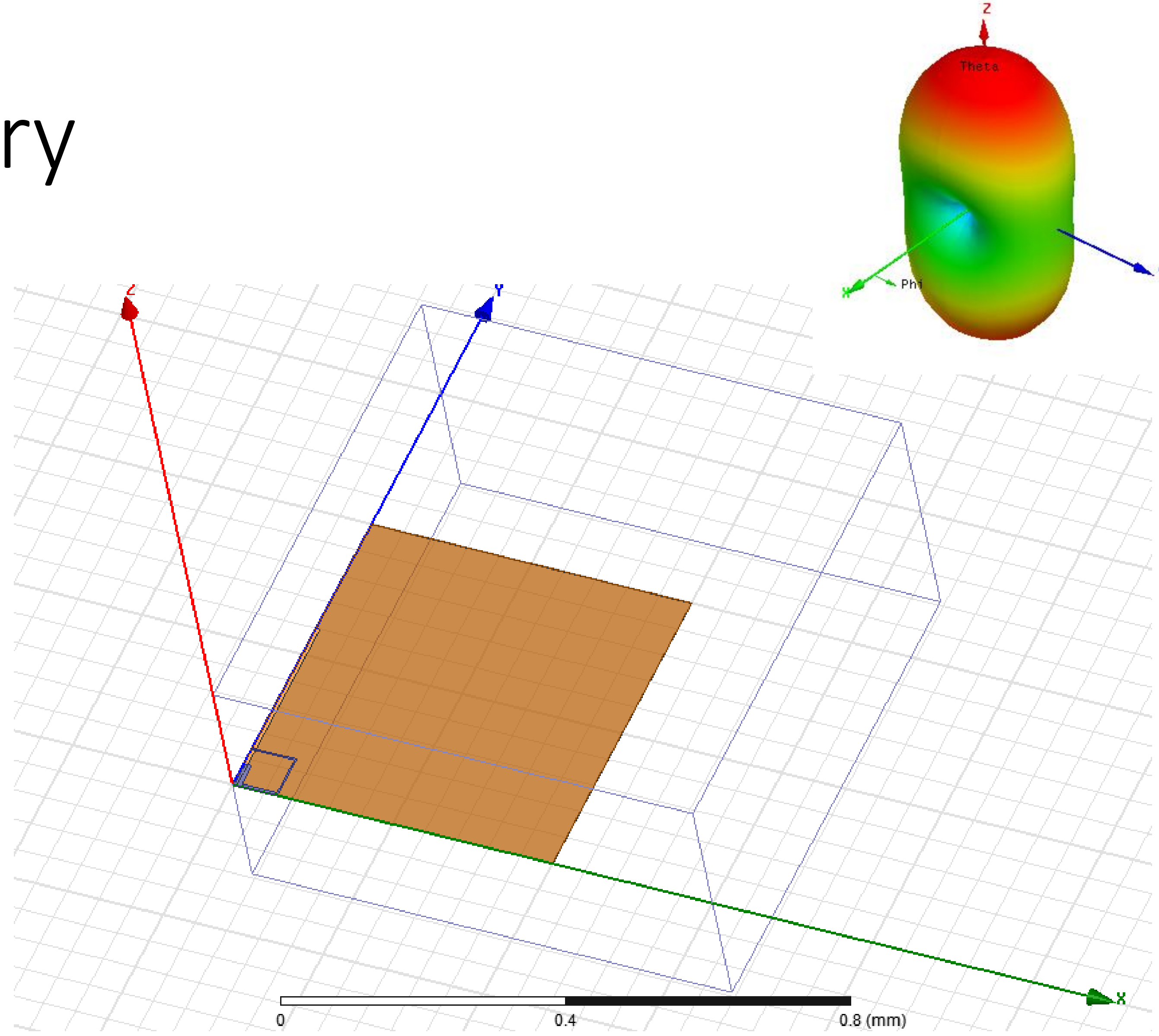
Thin-ish Film (4.2um)

High Frequency (5-20GHz)

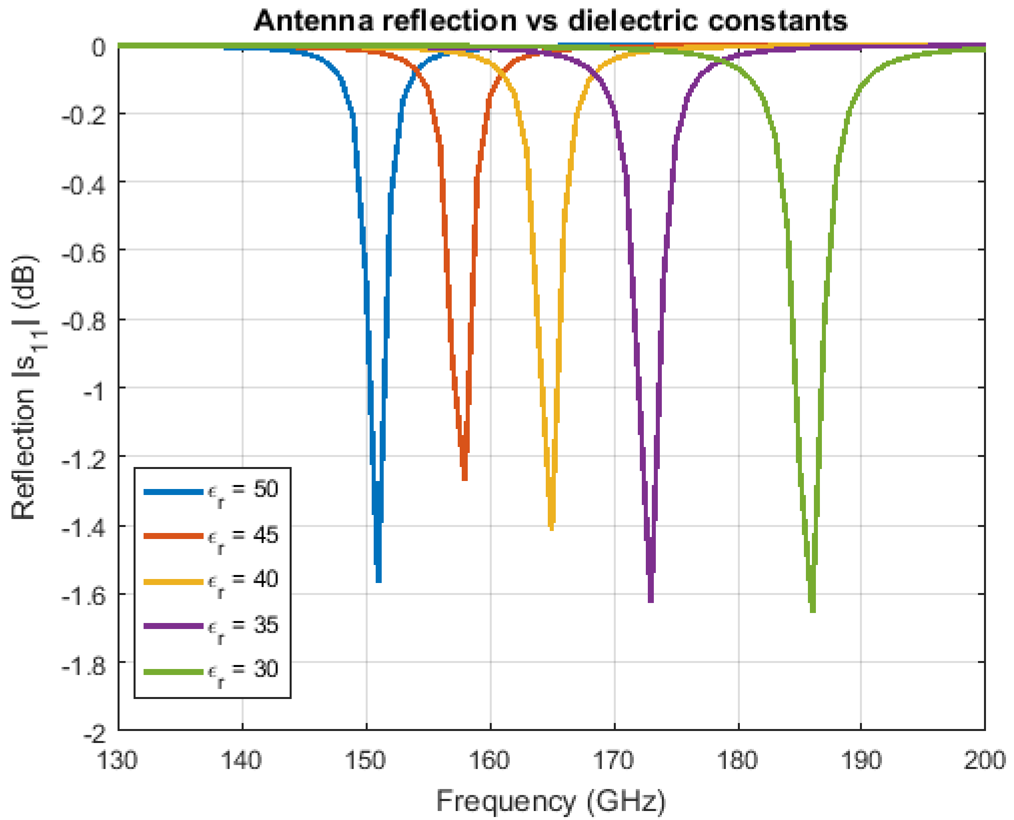
Characterization of SrTiO3 thin films at microwave frequencies using coplanar waveguide linear resonator method

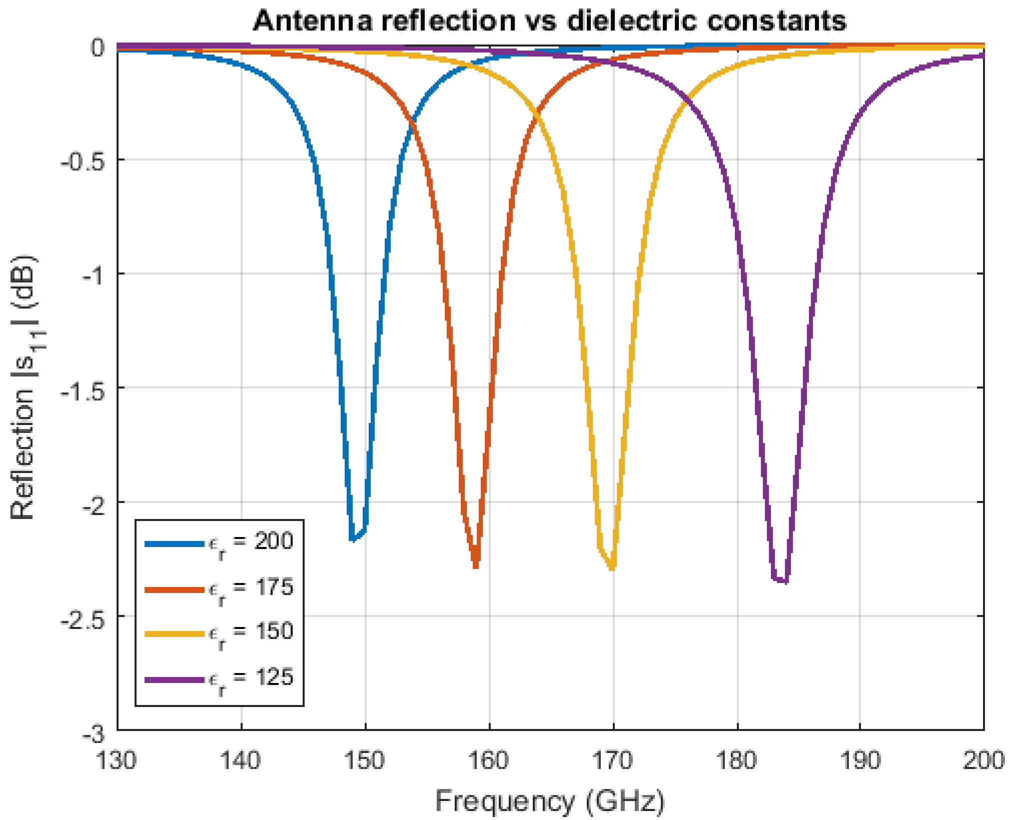
Simulation Geometry

- High dielectric constant next to two nearly resonant structures takes a lot of computational overhead
- Symmetry boundaries allow for factor of 4 reduction in mesh size
- Used a reasonably thin dielectric (1um)
  - Thick dielectrics may suffer from high microwave loss
  - Too thin dielectrics might suffer from crystal grains?



Demonstration of antenna scanning





- Tunability seems to be not an issue
- All papers I've seen demonstrate at least a 20% dielectric tunability – usually much more

What next?

- Material feasibility the obvious show stopper
  - No way of knowing without doing our own measurements
- Important calculations
  - Solve Laplace's equation to show DC biasing the STO substrate fills the area around the metamaterial
  - Substrate Modes. Ceramic-Si interface has large impedance mismatch
  - Kinetic inductance shifts detuning the metamaterial resonator
    - Hopefully not a real issue… past experience suggests kinetic inductance shifts are noticeable only for high Q circuits
- Model building
  - Create a microwave circuit model for antenna array
  - Sum antennas with proper phasing to construct beam pattern