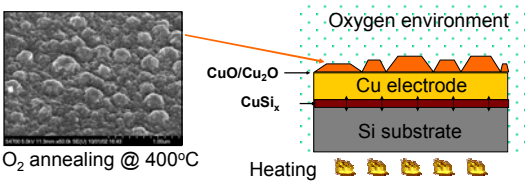
# Integration of Novel Cu-Based Electrode for $(Ba_xSr_{1-x})TiO_3$ Thin Film Devices

W. Fan[a,b], O. Auciello[a], J.A. Carlisle[a], S. Saha[a], B. Kabius[a], J.M. Hiller[a], R. Ramesh[c], R.P.H. Chang[b]
a) Materials Science Division, Argonne National Laboratory; b) Department of Materials Science and Engineering, Northwestern University;
c) Department of Materials and Nuclear Engineering, University of Maryland

## Advantages of Cu Metallization

- Low Resistivity
- Low Cost
- High electro-migration resistance
- High stress-migration resistance
- Easy etching process

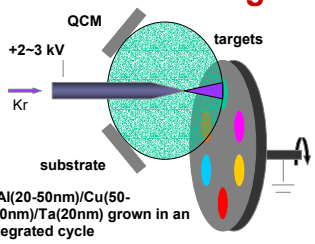
## Challenge for Cu / Oxide Film Integration




$O_2$ annealing @ 400°C

- Cu oxides easily in oxygen → Degradation of Cu electrical conductance
- Cu has significant diffusion rate into Si and $SiO_2$ → Contamination of Si chips

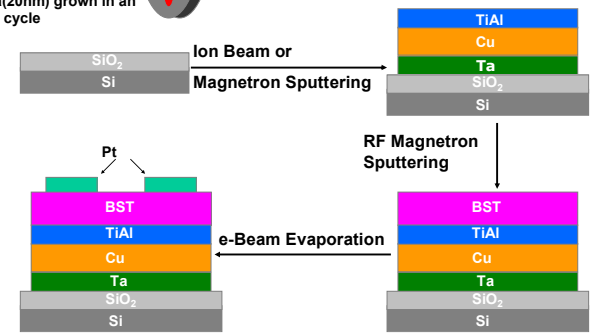
## Integration Strategies




TiAl(20-50nm)/Cu(50-200nm)/Ta(20nm) grown in an integrated cycle

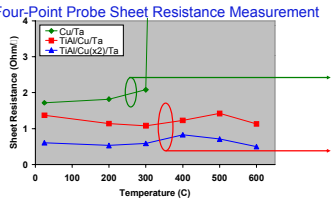
**Oxidation Barrier:**
TiAl – amorphous structure, good barrier

**Diffusion Barrier:**
Ta – thermodynamically stable with Si and Cu up to 700°C

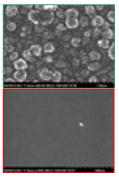



## Thermal Stability of Cu-Based Electrode

Four-Point Probe Sheet Resistance Measurement




Tested in furnace with 99.9% oxygen flow for 30 min.

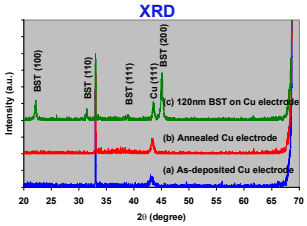


Bare Cu layer oxidized completely at 400 °C.

TiAl/Cu/Ta remains stable up to 600 °C.

- Electrode with 200 nm Cu layer exhibits low resistivity (2.7μΩ·cm) (Cu 1.7μΩ·cm / Pt 10.6μΩ·cm)
- Devices with Cu-based electrodes will have much lower RC constant and much faster switching speed than with Pt electrode

XRD

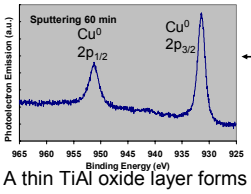


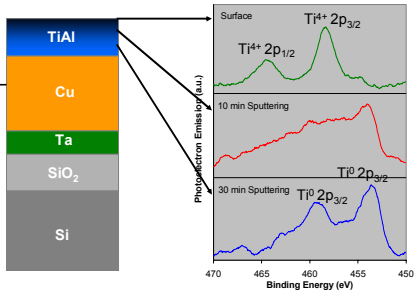

- Polycrystalline BST films were grown on TiAl/Cu/Ta electrodes
- Cu layer remained metallic through oxygen annealing and BST deposition
- No detectable interdiffusion between Cu and Si

** W. Fan, et al., Applied Physics Letters 82, 1452-1454 (2003)*

## Barrier Properties of TiAl

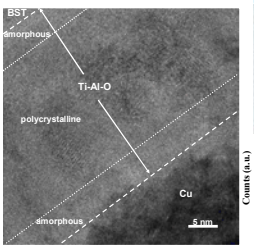
XPS Depth Profile of Heterostructured Electrode w/ Oxygen Annealing at 450°C

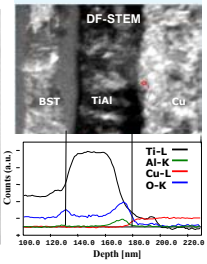


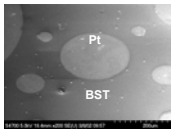

- A thin TiAl oxide layer forms at the TiAl barrier surface, and a transition from $TiO_2$ to Ti metallic XPS peaks is observed vs. depth
- Cu layer is intact and well confined between TiAl and Ta barriers
- Al and O segregate at the interface between TiAl and Cu
- Amorphous layer on both sides of the TiAl barrier prevents oxygen penetration and protects integrity of metallic Cu layer

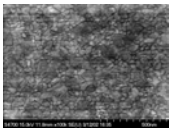
TEM of BST/TiAl/Cu/Ta Multilayers



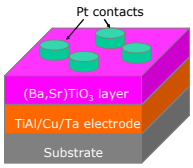

## Properties of BST Capacitors



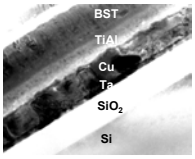
SEM of BST thin film surface

Top View




Side View

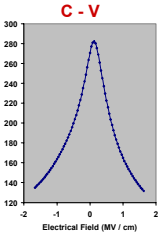
Cross-section TEM of BST/TiAl/Cu/Ta




- Polycrystalline BST thin film with 50~100 nm grains
- Clear interfaces between individual layers
- Smooth surface morphology

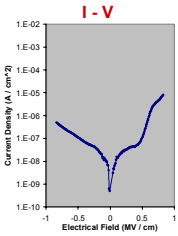
Dielectric Characteristics

C - V




- Dielectric constant: $\varepsilon_r = 280$
- Dielectric loss: tan $\delta = 0.007$
- Tunability: $(\varepsilon_{max} - \varepsilon_{min})/\varepsilon_{max} = 53\%$
- Leakage current : $J = 2\times10^{-8}$ A/cm$^2$ (±100 kV/cm)

I - V




## Summary

- TiAl and Ta layers show good oxidation and diffusion barrier properties, respectively, to enable integration of Cu electrode with BST films for fabrication of high frequency tunable devices.
- The heterostructured TiAl/Cu/Ta electrode exhibits low resistivity and good thermal stability through oxygen annealing up to 600 °C.
- For the first time, BST thin film capacitors with good dielectric properties achieved on TiAl/Cu/Ta electrode.
- Cu-based electrode can also be used for integration of ferroelectric and other complex oxide films with Si-based devices.

BES - DOE

This work was supported by the U. S. Department of Energy, Basic Energy Sciences, under contract W-31-109-ENG-38

MSD - ANL