2D Materials for BEOL Applications

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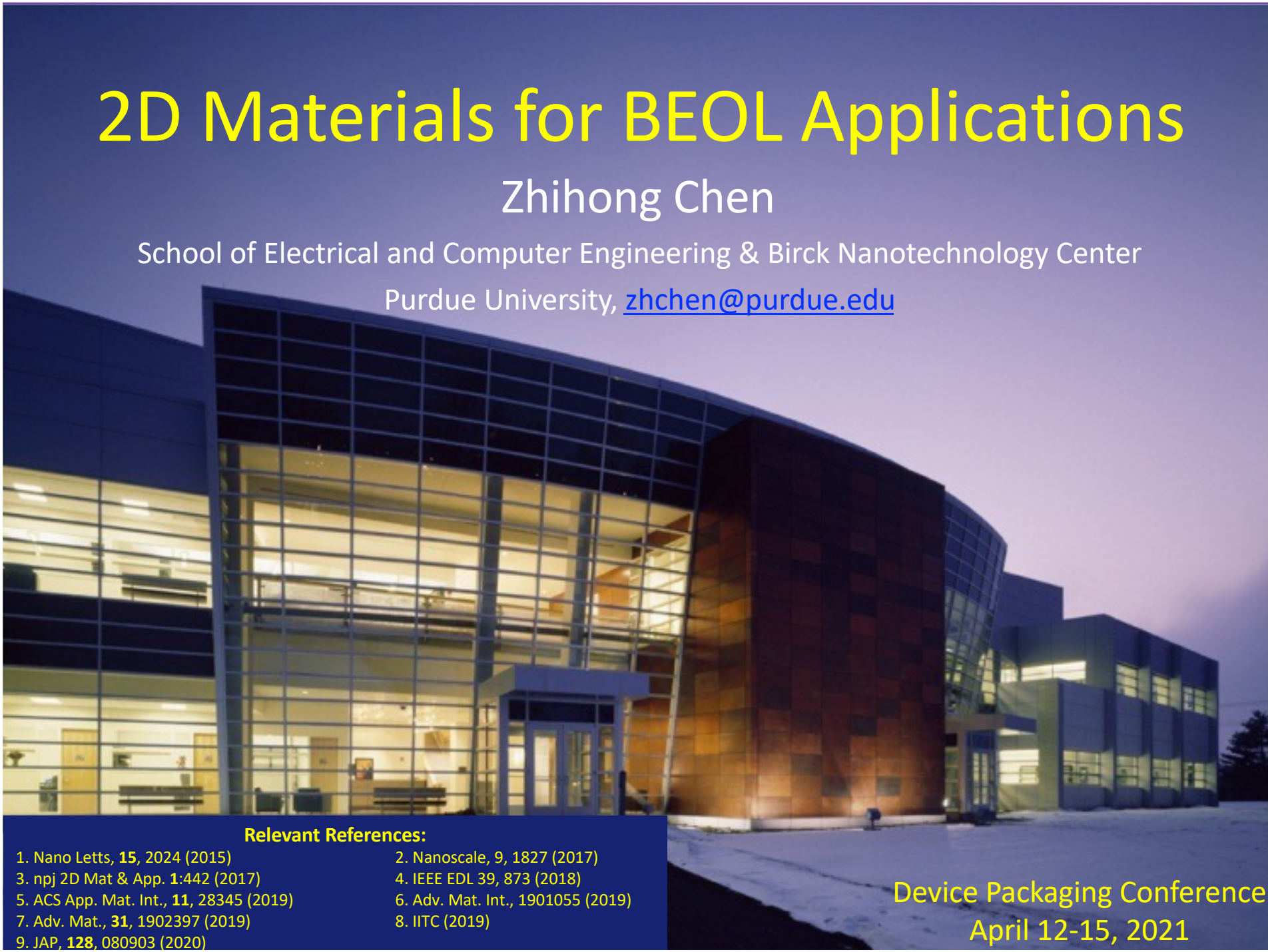
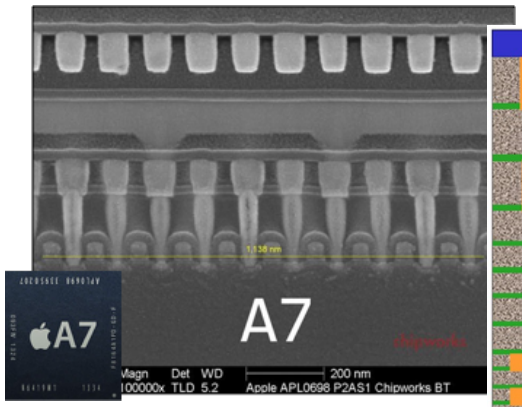


Relevant References:

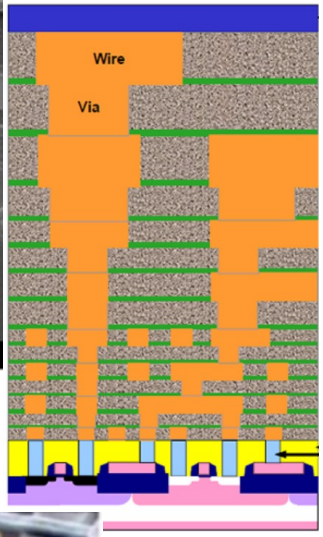
1. Nano Letts, **15**, 2024 (2015)
2. Nanoscale, 9, 1827 (2017)
3. npj 2D Mat & App. **1**:442 (2017)
4. IEEE EDL 39, 873 (2018)
5. ACS App. Mat. Int., **11**, 28345 (2019)
6. Adv. Mat. Int., 1901055 (2019)
7. Adv. Mat., **31**, 1902397 (2019)
8. IITC (2019)
9. JAP, **128**, 080903 (2020)

Device Packaging Conference
April 12-15, 2021

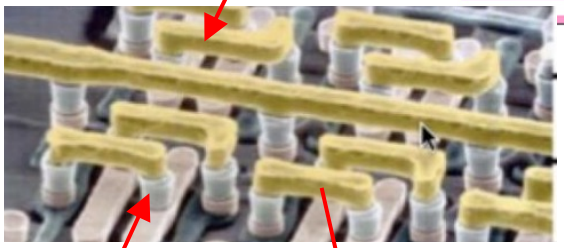
Challenges in BEOL Interconnect Technologies

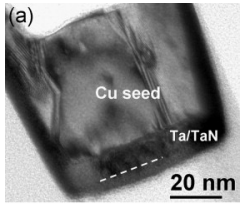


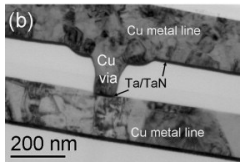
ITRS 2005



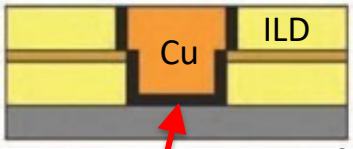
Cu interconnects





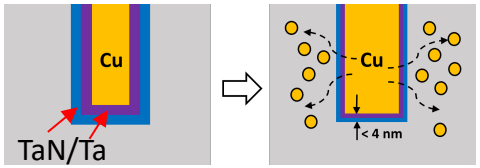


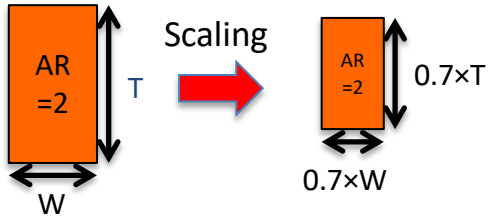
via

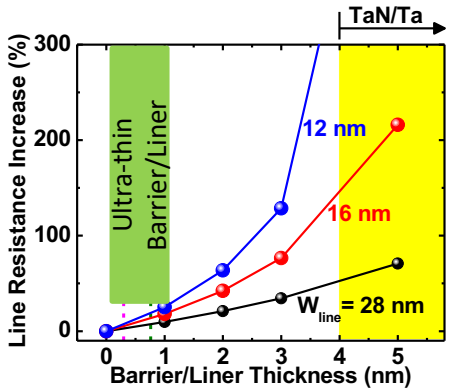


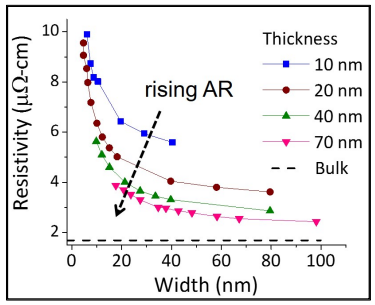
Mat. Sci. Semi. Proc, **27**, 860 (2014)

Diffusion Barrier/Liner Bilayer (TaN/Ta)









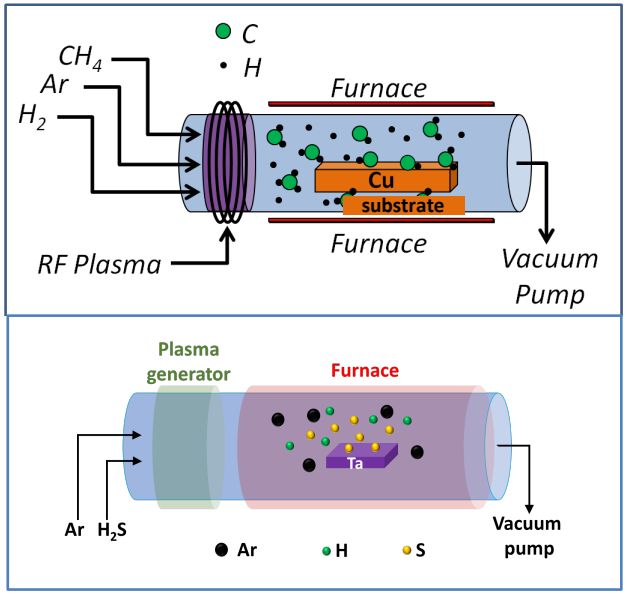
- Conventional barrier/liner > 4nm
- Increasing Cu resistivity at scaled dimensions

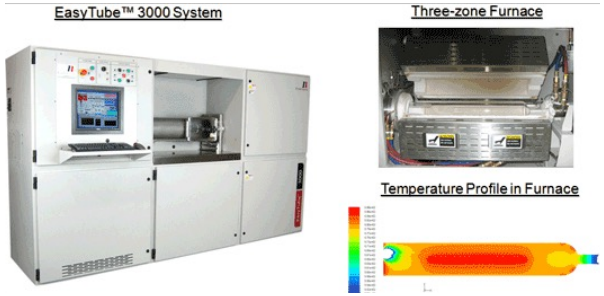
Line resistance↑ electromigration↑ Joule heating↑

Atomically thin 2D diffusion barrier!

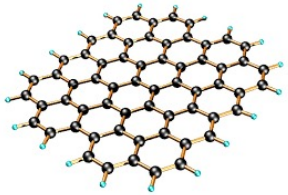
BEOL Compatible 2D Material Growth

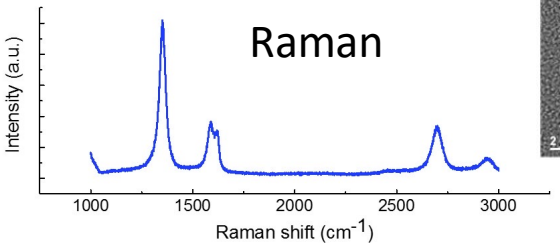
Plasma Enhanced Chemical Vapor Deposition (Graphene, TaS_2, MoS_2 growth)

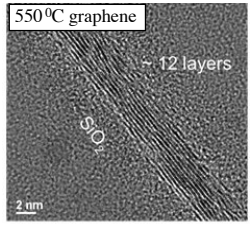




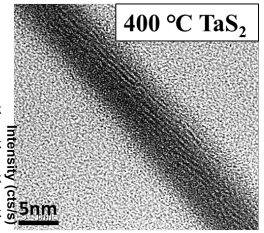
Graphene (0.3nm)



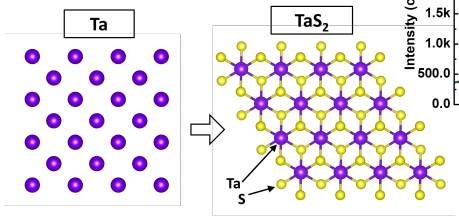


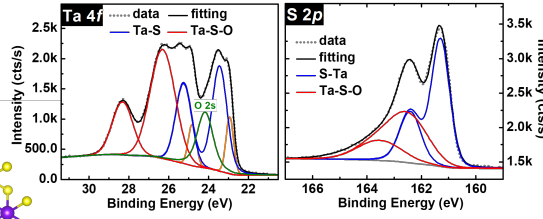


TEM



TaS_2 (0.7nm)



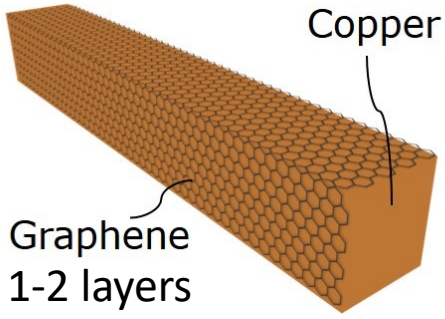


XPS

- 2D materials growth on arbitrary substrates
- BEOL compatible low temperature growth (400 – 550 ^{0}C)
- Enhance electrical conductivity of Cu/Co interconnects
- Inhibit Cu diffusion into dielectrics
- Graphene enhances thermal conductivity of Cu interconnects

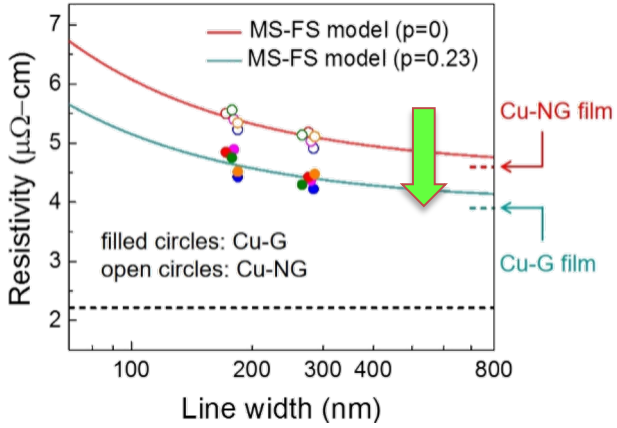
Chugh, et al., Carbon, **93**, 393 (2015)
Lo, et al., Advanced Materials, **31**, 1902397 (2019)

Summary of Graphene Properties for BEOL Interconnect Technologies

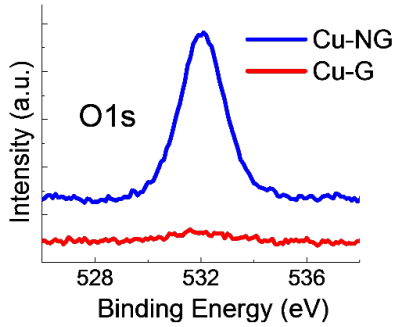


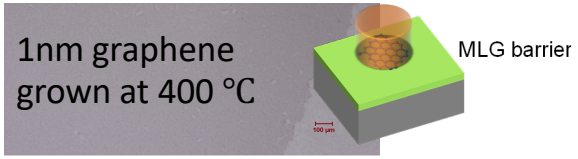
Mehta, et al., Nano Letts, **15**, 2024 (2015)

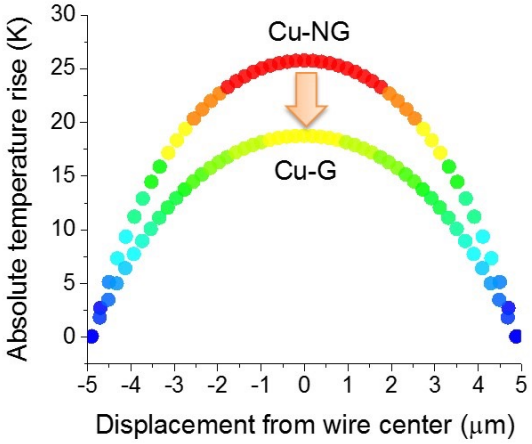
Reduced surface scattering



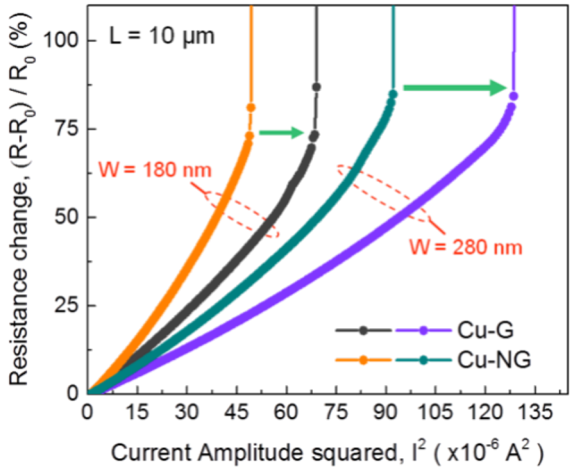
Prevent Cu oxidation



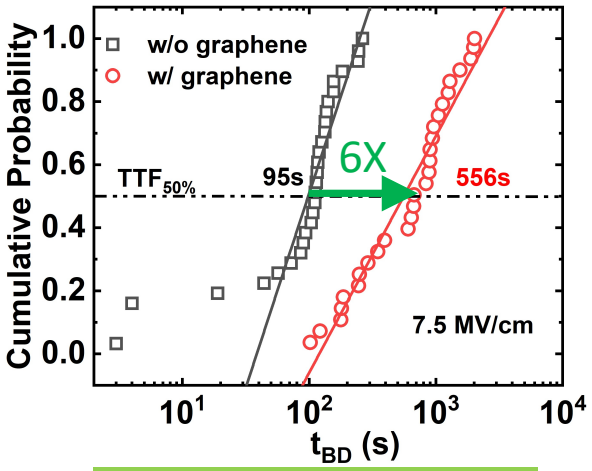




Reduced Joule heating

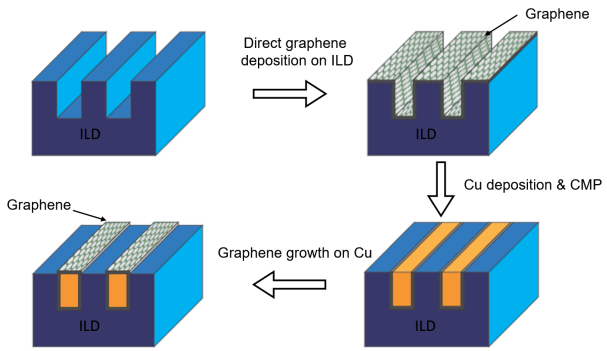


Increased breakdown strength

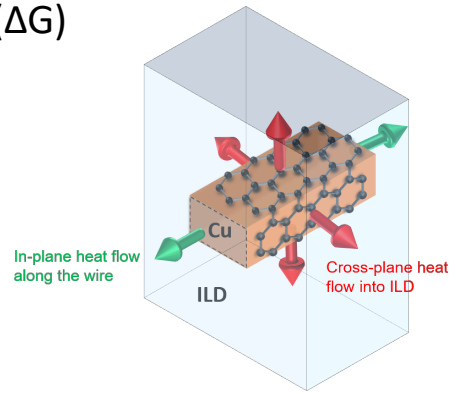


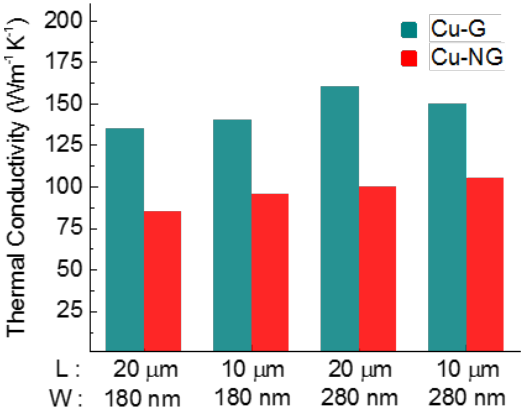
Mitigate Cu diffusion

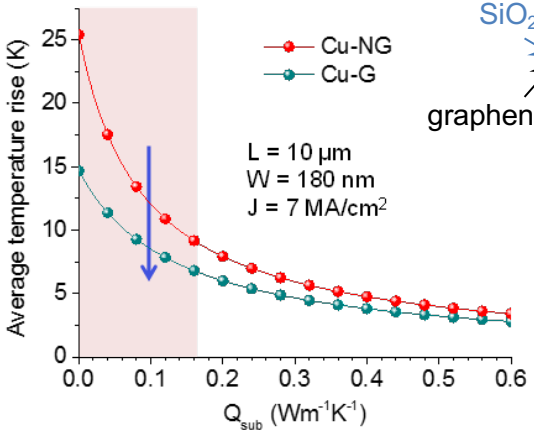
BEOL Thermal Management Through Graphene

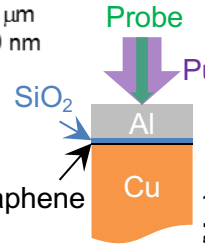


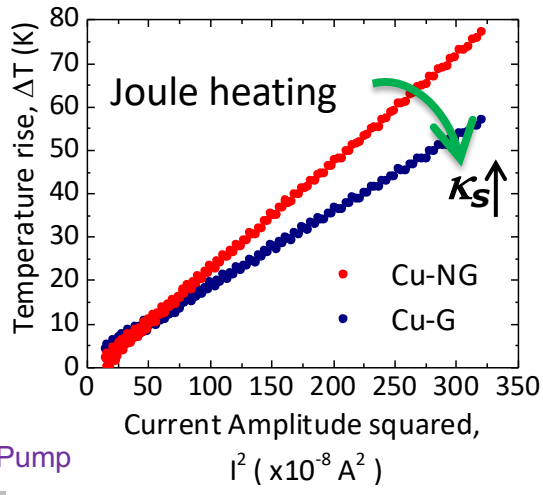
- Reduced κ_S for scaled Cu wires
- Enhancement from graphene with high thermal conductivity (κ_S) and thermal boundary conductance (ΔG)

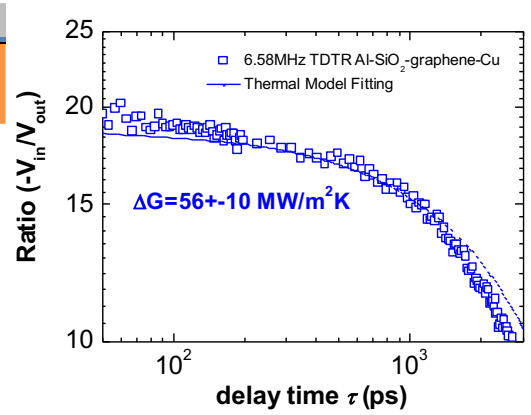








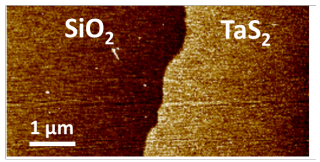


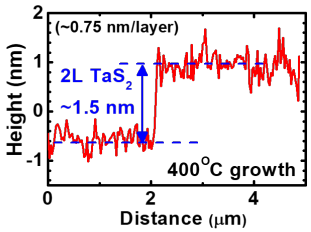


$\Delta G_{SiO2\text{-}G\text{-}Cu}$ ~ 100 MW/m²K

- Graphene passivated Cu wires (Cu-G) show less Joule heating – lower **ρ** and higher κ_S
- High thermal boundary conductance has been measured at SiO2-Graphene-Cu interfaces

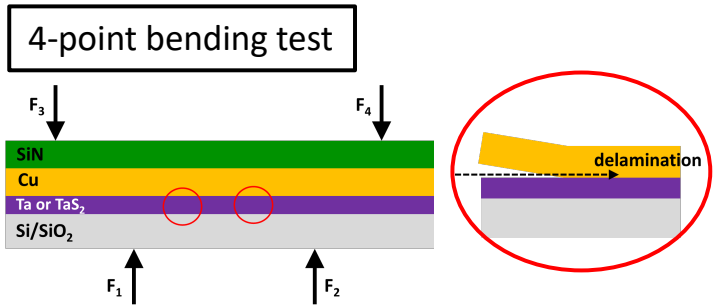
Summary of TaS_2 Properties for BEOL Interconnect Technologies

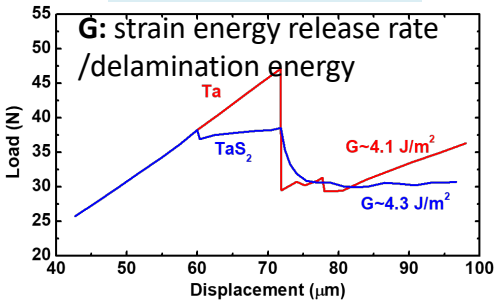




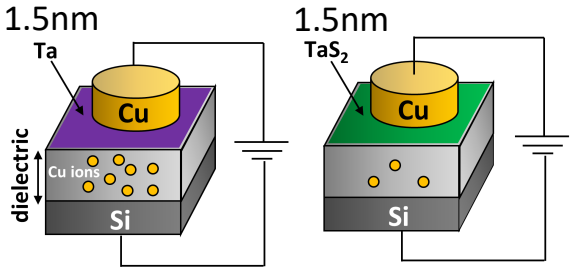
(Collaboration with Intel)

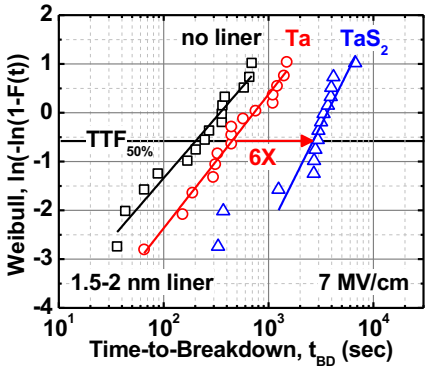
Liner properties



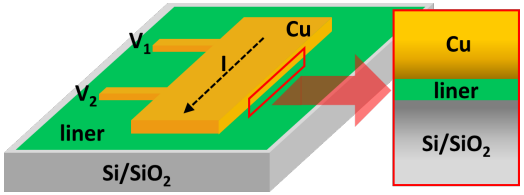


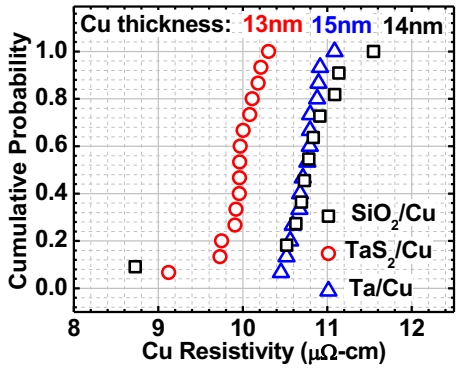
Diffusion barrier properties





Electrical properties





- Excellent Cu diffusion barrier properties -- 6x more efficient than Ta barrier
- Excellent wetting and adhesion to Cu and dielectrics
- Reduces Cu and Co resistivity by suppressing surface scattering