GRAPHENE AS A CORROSION INHIBITOR

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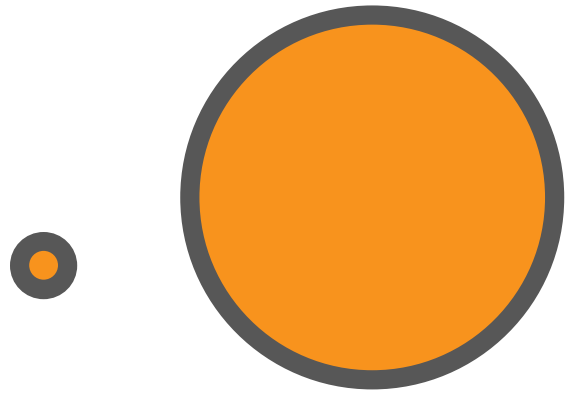
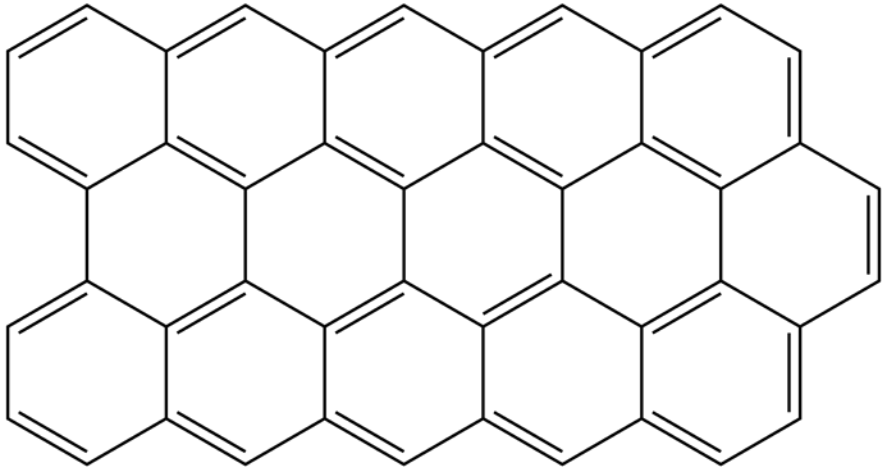
Motivation

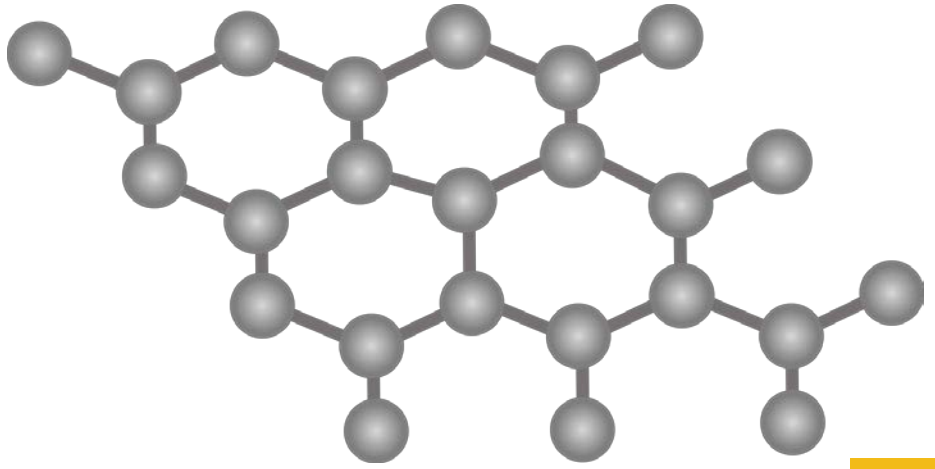
- Corrosion costs billions a year
- Microelectronics highly susceptible
  - Smaller surface area, thickness = bigger impact from corrosion
  - 20% of all microelectronic device failures
- Safety concerns
  - Air bag failure – components corrode
- Physical corrosion barriers
  - Paint = too thick



Graphene

- Physical barrier against corrosion
- 2D material, one atom thick
- Carbon in hexagonal crystal lattice
- Relatively new material
  - First isolated from graphite in 2004, 2010 Nobel Prize

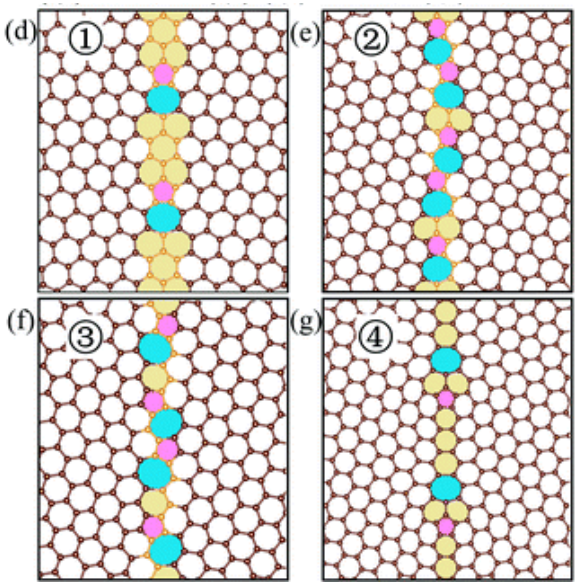


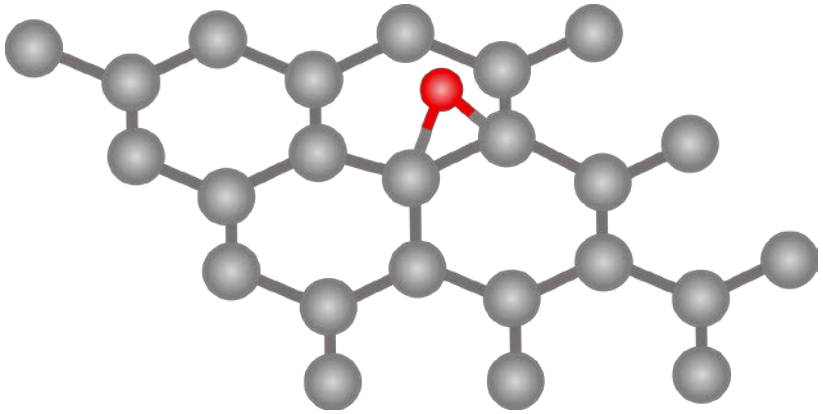


Graphene Defects

- Where corrosion begins
  - Better quality graphene = less defects = less corrosion
- Graphene already has grain boundary defects
- Inducing through ozone exposure
  - O_3 + graphene (C-C) ⟶ C-O-C epoxy complex + O_2
  - Point defects

Grain Boundaries

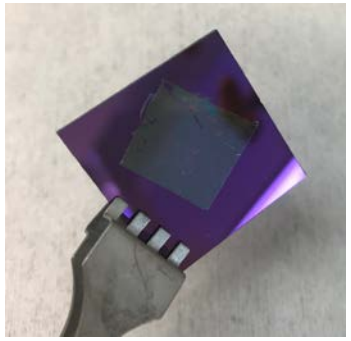




IEEE TRANSACTIONS ON NUCLEAR SCIENCE, VOL. 58, NO. 6, DECEMBER 2011 Point defects: *Nanoscale*, 2017, **9**, 13725-13730 Grain b.: *Nanoscale*, 2014, **6**, 4309-4315

Methods

Graphene growth on Cu Foil



Ozone treatment of graphene on Cu

Transfers (graphene on SiO_2 wafers)

Raman – peak ratios

Thermal **Corrosion Tests** (Graphene on Cu foil)

CONTROL: Annealed copper, no graphene

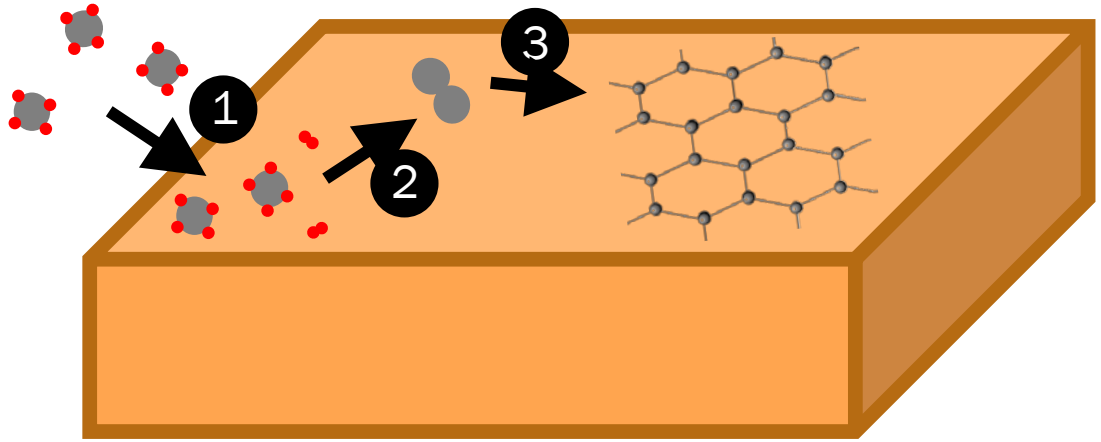
SEM – qualitative

XPS – degree of corrosion

Graphene Growth on Copper

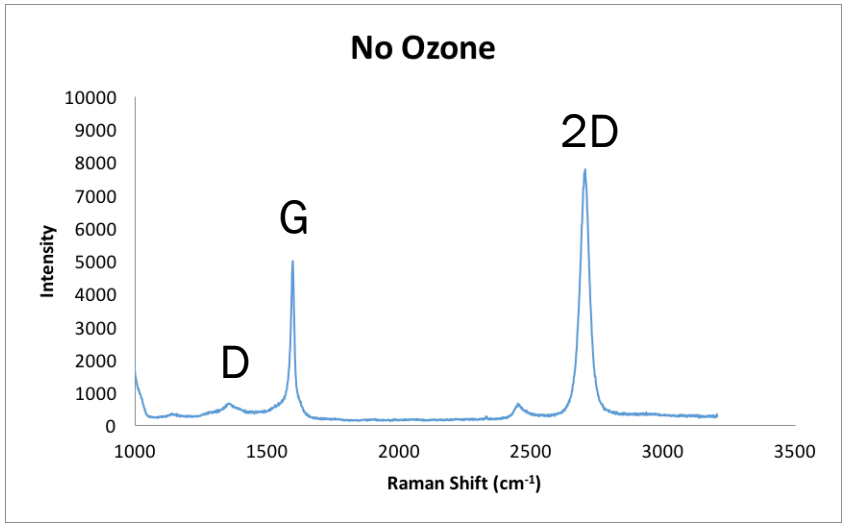
- Chemical Vapor Deposition, CVD, at 1000 °C (MP_{Cu} = 1085 °C)
- Low pressures – 250 mtorr
- Growth gases: CH_4 (carbon source) and H_2
- Copper favors single coalesced layer because solubility of gases used

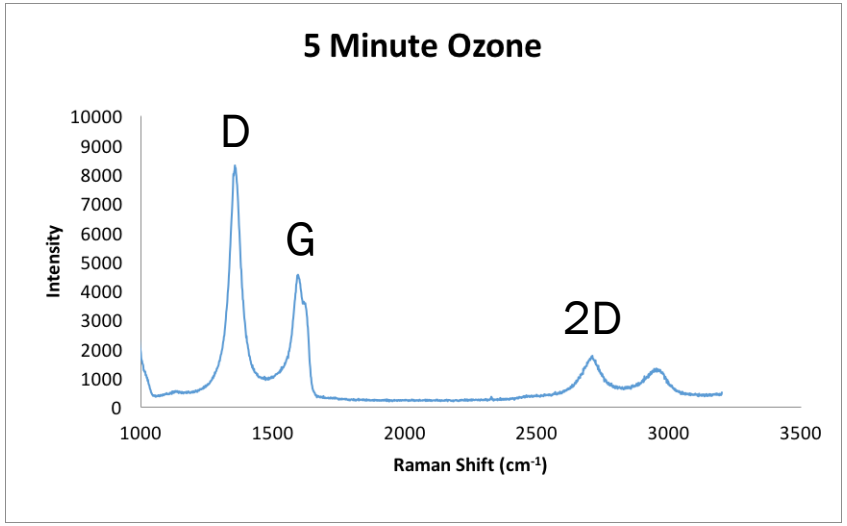
1. Adsorption of CH_4
2. Dehydrogenation
3. Nucleation and growth



Raman Spectroscopy

- Transfers
- Quality and type of graphene based on peak sizes and ratios
- Defect density – D to G peak height ratio



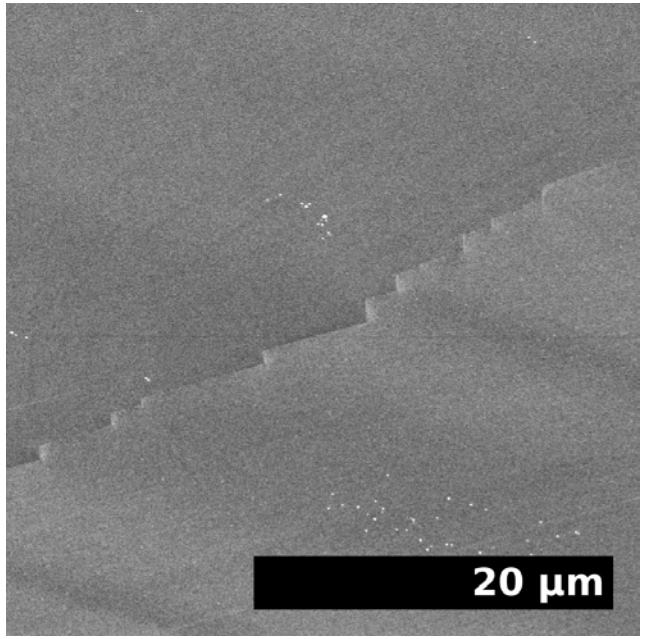


Minutes of Ozone Exposure	D to G Intensity Ratio	Defects per square micron
0	0.07	284
5	1.89	7665

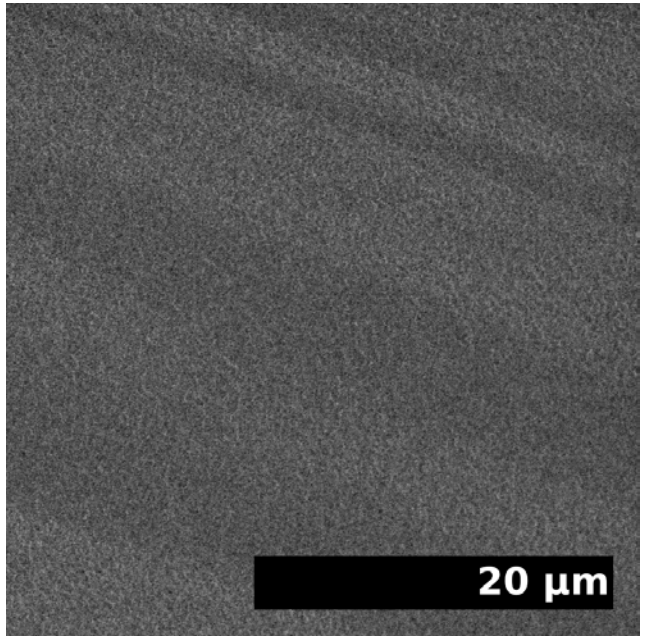
SEM for Corrosion Experiment

- Control: Annealed copper, no graphene

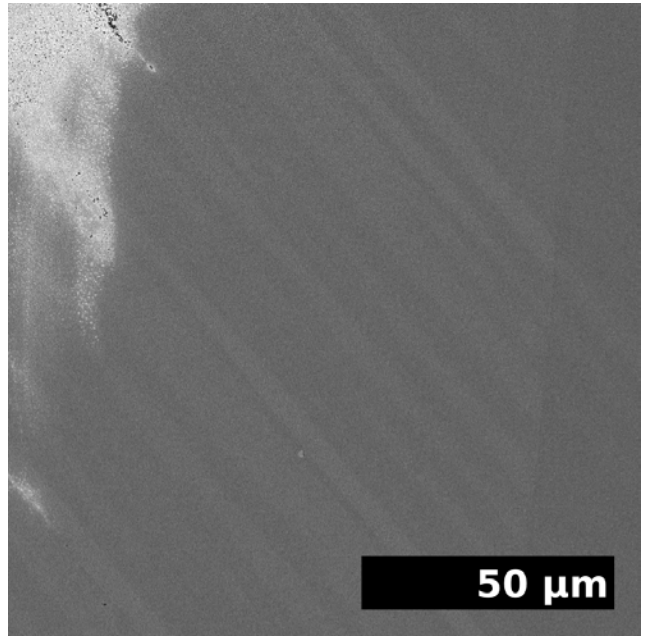
Before hot plate



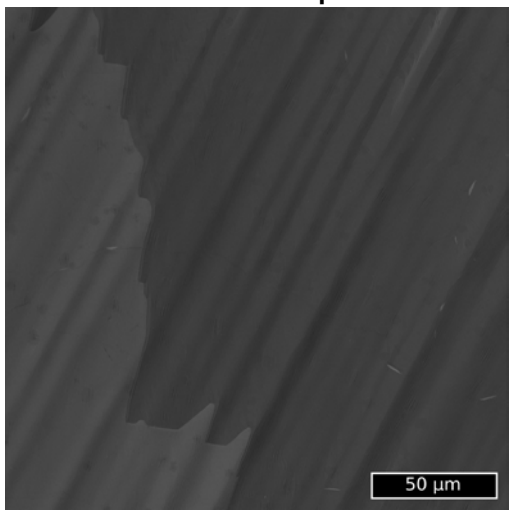
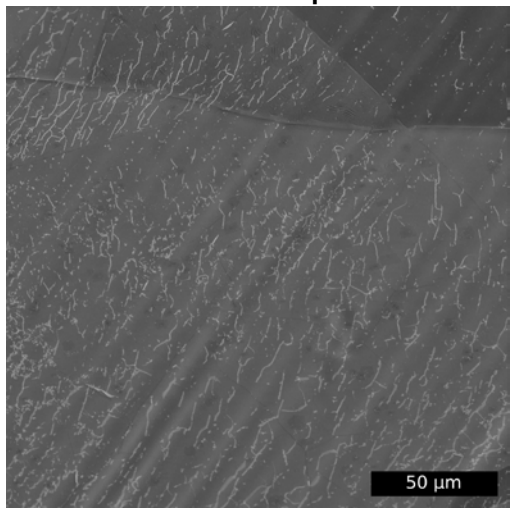
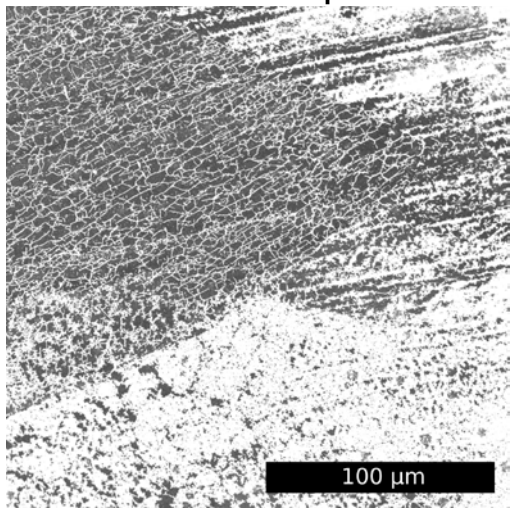
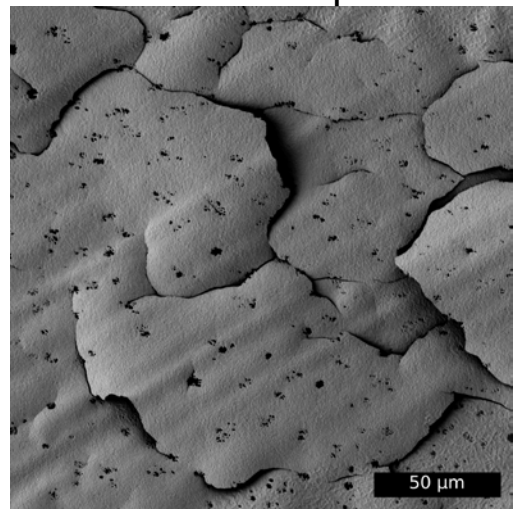
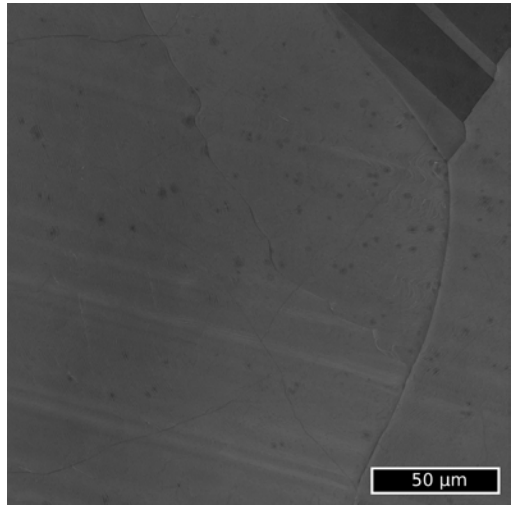
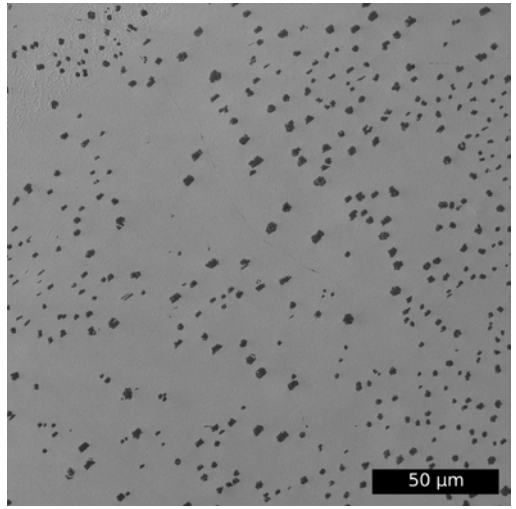
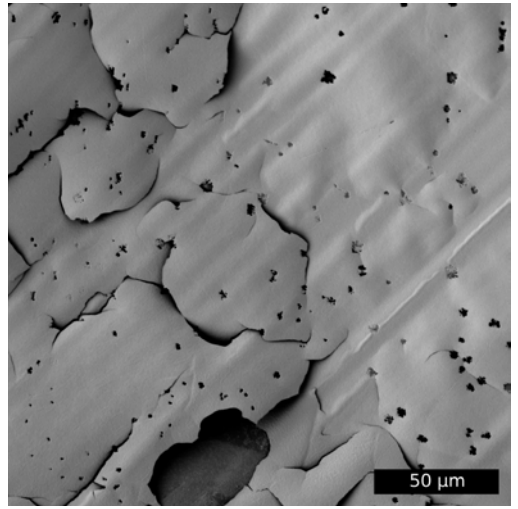
2 min hot plate



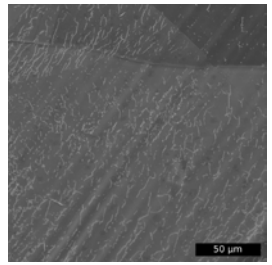
10 min hot plate



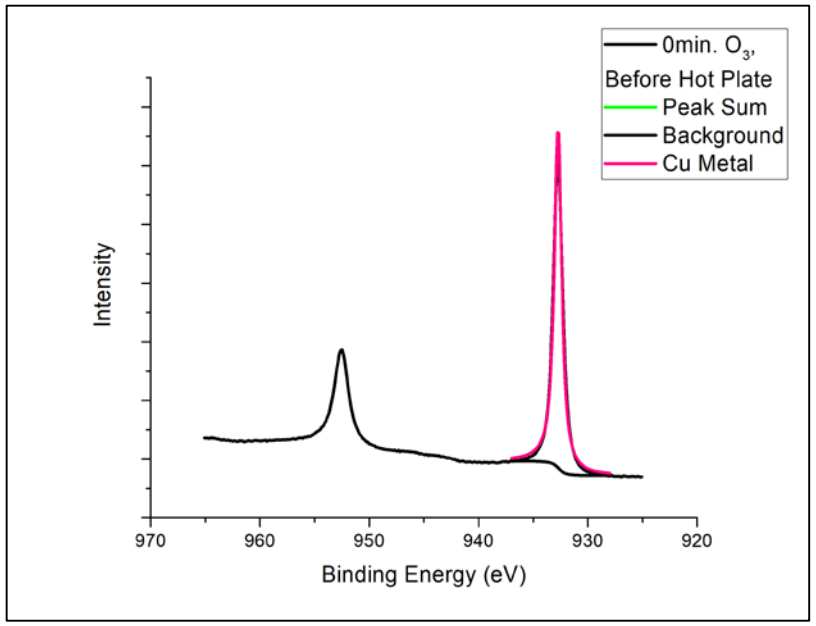
SEM for Corrosion Experiment

	Before hot plate	2 min hot plate	10 min hot plate	30 min hot plate
No Ozone				
5 min. Ozone				

X-ray Photoelectron Spectroscopy: No Ozone

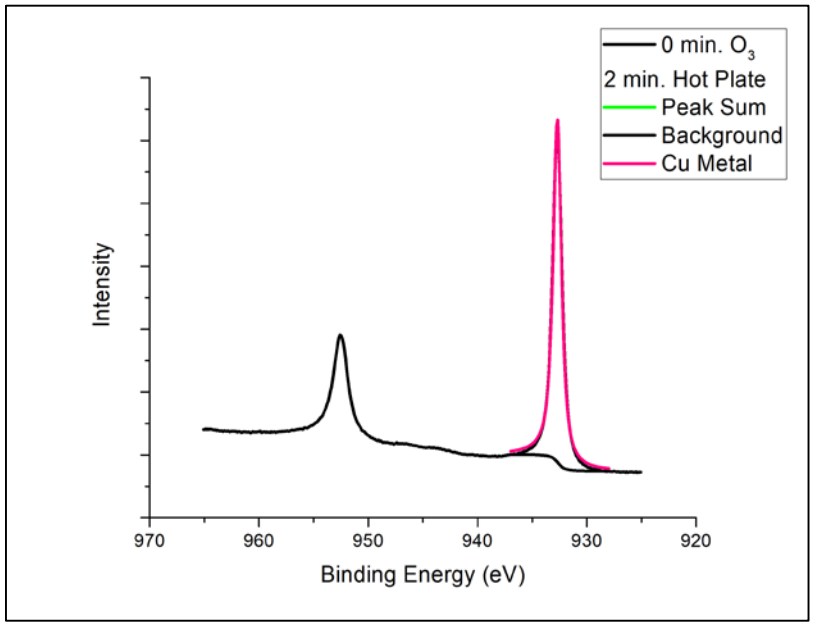


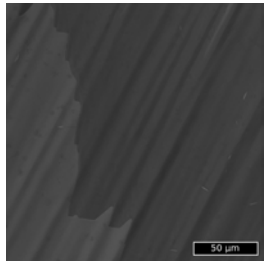
Before hotplate



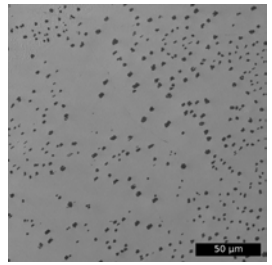
2 min
hot plate

2 min hotplate

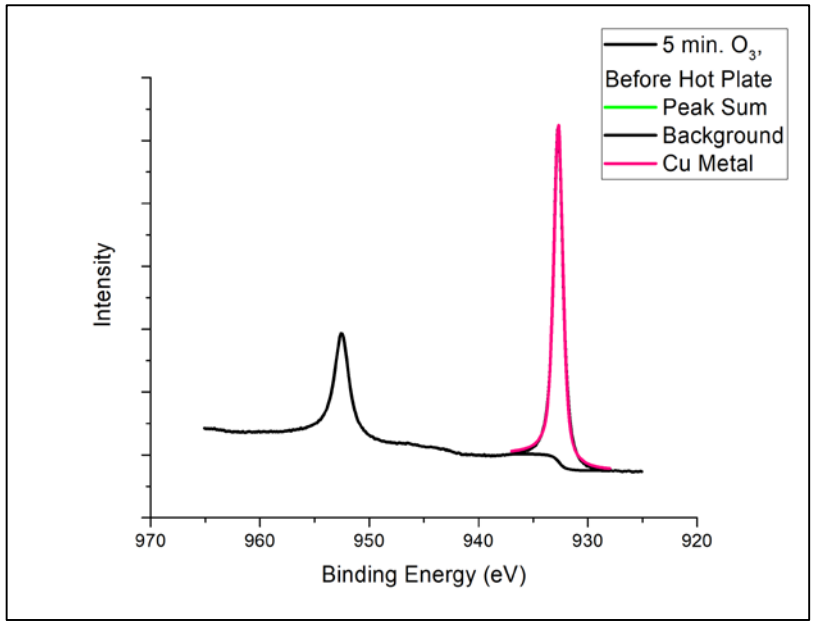




X-ray Photoelectron Spectroscopy: 5 min. Ozone

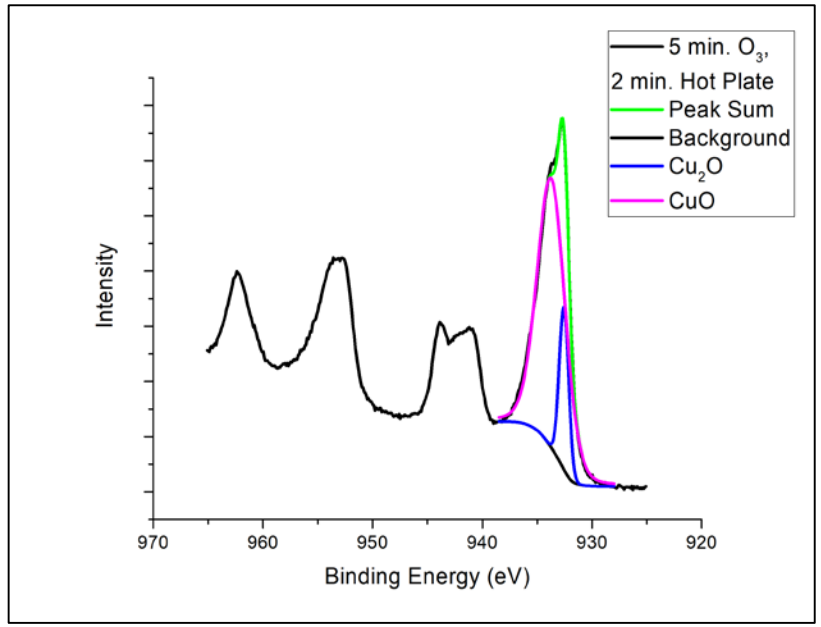


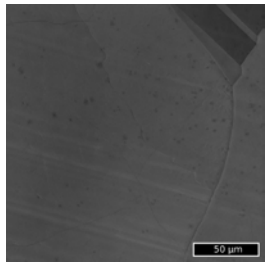
Before hotplate



2 min hot plate

2 min hotplate





Conclusions

- Ozone exposure increases defects
- **Defective graphene is less effective corrosion barrier**

Future Work

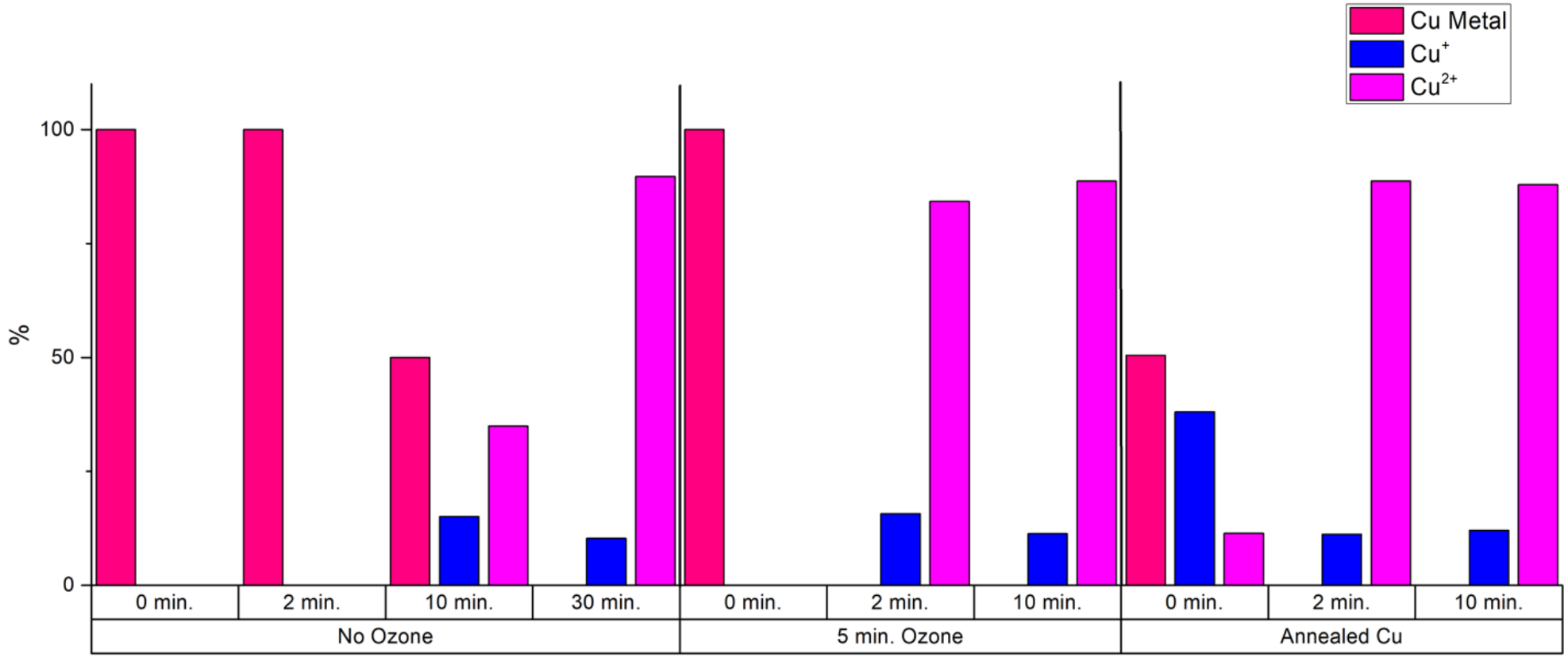
- Perform electrochemistry experiments - corrosion rates
- Test graphene's corrosion protection for other metals
  - Nickel, steel
- Compare effectiveness of other 2D materials as corrosion barriers
  - Hexagonal boron nitride
  - Multilayer graphene

QUESTIONS?

SUPPLEMENTAL SLIDES

XPS Summary

Oxide Percentages in Corrosion Experiment



Scanning Electron Microscopy, SEM

- Arrested growth – 15 minutes
- 170 μm^2 on average