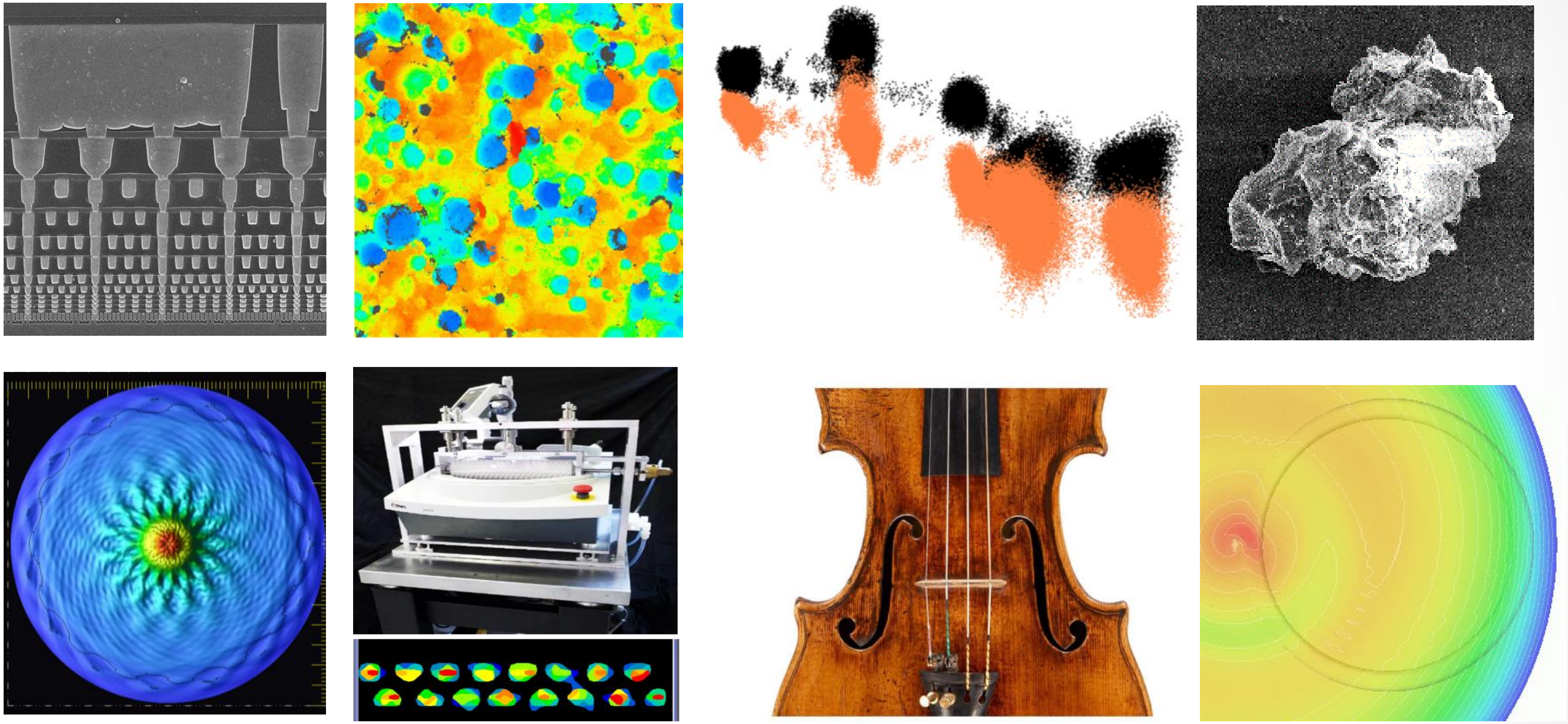
An Eleven Module Course on CMP Fundamentals



Prof. Ara Philipossian

Course Outline

Module I –	Historical overview – Why and how CMP came about – And a look into the future
Module II –	Definitions of terms
Module III –	Review of selected experimental evidence with the goal to introduce and discuss observations that form the basis for a conceptual understanding of CMP phenomena and removal rate models
Module IV –	Bulk polishing theory with the goal to apply a proper model for oxide and metal removal
Module V –	Fundamentals of Pads
Module VI –	Tribology of CMP and nano-particle settling in slurries
Module VII –	Advanced topics in CMP
Module VIII –	Reactor design and modeling
Module IX –	Fundamentals of gritted diamond and CVD-coated discs for pad conditioning
Module X –	Fundamentals of retaining rings
Module XI –	Fundamentals of post-CMP cleaning

Module I – Outline

A historical perspective and a look into the future

- IC fabrication and the need for CMP
- Early device isolation issues and the invention of STI
- Brief look at CMP equipment, consumables and the dimensions of things involved
- The 2022 IRDS and where to find more information
- Selected CMP nanoparticle synthesis pathways
- Frank William Preston and his equation
- Some basic CMOS device cross-sections

Module II – Outline

Definition and example structures

- The CMP module
- Step height and local planarity
- Local vs. global planarity
- Pattern density vs. step height
- Wafer-level vs. die-level planarity
- Planarization length
- Dishing, erosion, field oxide loss, edge-over-erosion
- Methods of measuring the above
- Effects on electrical properties
- The STI process steps
- Asperity filtering
- STI CMP simulations and time-elapsed evolution re: PL and PE
- More on asperity filtering
- The dual-damascene structure

Module III – Outline

Review of selected sets of experimental evidence with the goal to introduce and discuss observations that form the basis for a conceptual understanding of CMP phenomena and CMP models

- Mainstream CMP tools and associated mechanics
- Basic observations of bulk pad structure and pad topography
- Pad bulk mechanical properties vs. surface mechanical properties
- Thermal measurements
- Partial lubrication of contacting asperities
- Shear and normal force measurements
- Vibrational measurements
- Polisher impact hammer studies and harmonics
- Motor current measurements
- Use of frictional and vibrational data for EPD (STI and Cu)
- EPD methods based reflectance and eddy current (EC)

Module IV – Outline

Bulk polishing theory with the goal to apply proper removal rate models for oxide and metal polishing

- Examples of ILD and metal polishing data
- Preston plots vs. contour (Lim-Ashby) plots
- High-level derivation and application of a simple tribochemical model
- Mechanically-limited and chemically-limited extremes of the model
- Heat transfer to contacting summits and the definition of “flash heating”
- Analytical estimate of contacting summit temperature and mean reaction temperature
- Direct calculation of reaction temperatures
- Several case studies
- Occam’s Razor

Module V – Outline

Pads

- Bulk and surface mechanical properties of hard pads such as D100 and IC1000
- Surface water absorption due to exposure to ultra-pure water (UPW)
- Pad surface mechanical response to loading and unloading of dead weights
- Role and effect of grooves – Some examples
- Characterization of pad surfaces with confocal microscopy
- Surface height probability density functions
- Pad summits and their characteristics
- Pad-wafer contact area measurements
- Selected case studies
- Real-time spent slurry extraction

Module VI – Outline

Tribology in CMP and the Components of COF

- Stribeck curves
- Sommerfeld and pseudo-Sommerfeld numbers
- Stribeck+ curves
- Corrections regarding the two curves noted above
- Force cluster plots and their applications in CMP
- Directivity curves
- Kinetic curves

Criteria for Nano-Particle Settling in CMP

- Stokes number and estimation of abrasive nano-particle settling tendencies
- Slurry flow and residence times in grooves
- Terminal and settling velocities of particles in fluids

Module VII – Outline

Advanced Topics in CMP

- Heat transfer mechanisms in rotary polishers
- Differences in temperature and slurry age re: multi-point vs. single-point slurry injection on IC and Fujibo pads
- Pad bulk and surface mechanical properties
- Some of the ramifications of migrating to 450 mm wafers
- Force clusters and the hidden orbits within them
- Fluid dynamic ramifications
- Wafer attitude (i.e. altitude, pitch and bank) during polishing
- Wafer curvature during polishing
- Detecting differences in tungsten film structure while polishing
- Determining “instantaneous” removal rates in copper and tungsten polishing

Module VIII – Outline

Reactor design and modeling for CMP

- The pad-slurry-wafer interface as a chemical engineering reactor
- The residence time distribution (RTD) technique
- Definitions, derivations and applications of slurry mean residence time, dispersion number, turnover ratio and slurry utilization efficiency
- Case studies re: the effects of flow rate, groove geometry, polish time, pressure and sliding velocity on the above (and key polishing outcomes)

Module IX – Outline

Fundamentals of Pad Conditioning

- ILD polish rate decay
- Pad surface micro-texture evolution as a result of polishing and conditioning
- Characterization of active and aggressive diamonds
- The study of furrows cut in the pad as a result of conditioning
- Conditioning, conditioner wear and RR performance
- Pad debris and fragments from conditioning
- Particulate generation
- Issues re: disc size and platen size
- Conditioning recipe optimization

Module X – Outline

Fundamentals of Retaining Rings

- Materials of construction and main functions
- How do retaining rings work and how certain designs may affect polishing outcomes
- Bow waves and hydrodynamic boundary layers
- The Stribeck+ curve applied to retaining rings
- Tribological, thermal and kinetic attributes of PEEK and PPS AMAT Reflexion rings for ILD and Cu applications
- Tribological, thermal and kinetic attributes of PEEK and PPS AMAT Reflexion rings for ILD and W applications

Effect on pad cut rate (PCR) and ring wear rate (RWR)
SEM of pad debris AND ring debris generated due to disc wear AND ring wear
Effect of retaining rings on pad micro-texture

Module XI – Outline

Fundamentals of Post-CMP Cleaning

- General criteria for effective wet cleaning
- The many types of defects, slurries, and wafers
- Zeta-[potential and the isoelectric point (IEP)
- Sonic agitation
- PVA brush cleaning and the underlying mechanism
- Defects induced by PVA cleaning
- Organic residues in post-CMP cleaning
- Undercutting
- Results from a mega-fab and fundamental explanation of the results
- Fundamentals of PVA scrubbing and issues to deal with
- Use of supramolecular assemblies in cleaning solutions
- Utility of force time traces and FFTs