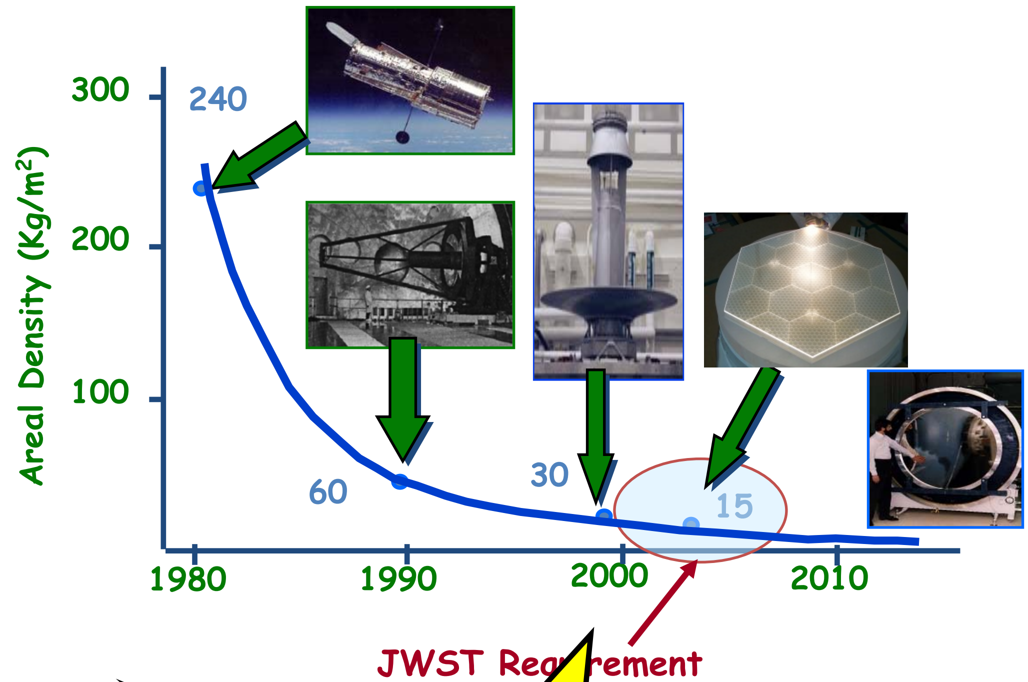

RAPT
INDUSTRIES
when speed and precision matter RAPT Industries
www.raptindustries.com

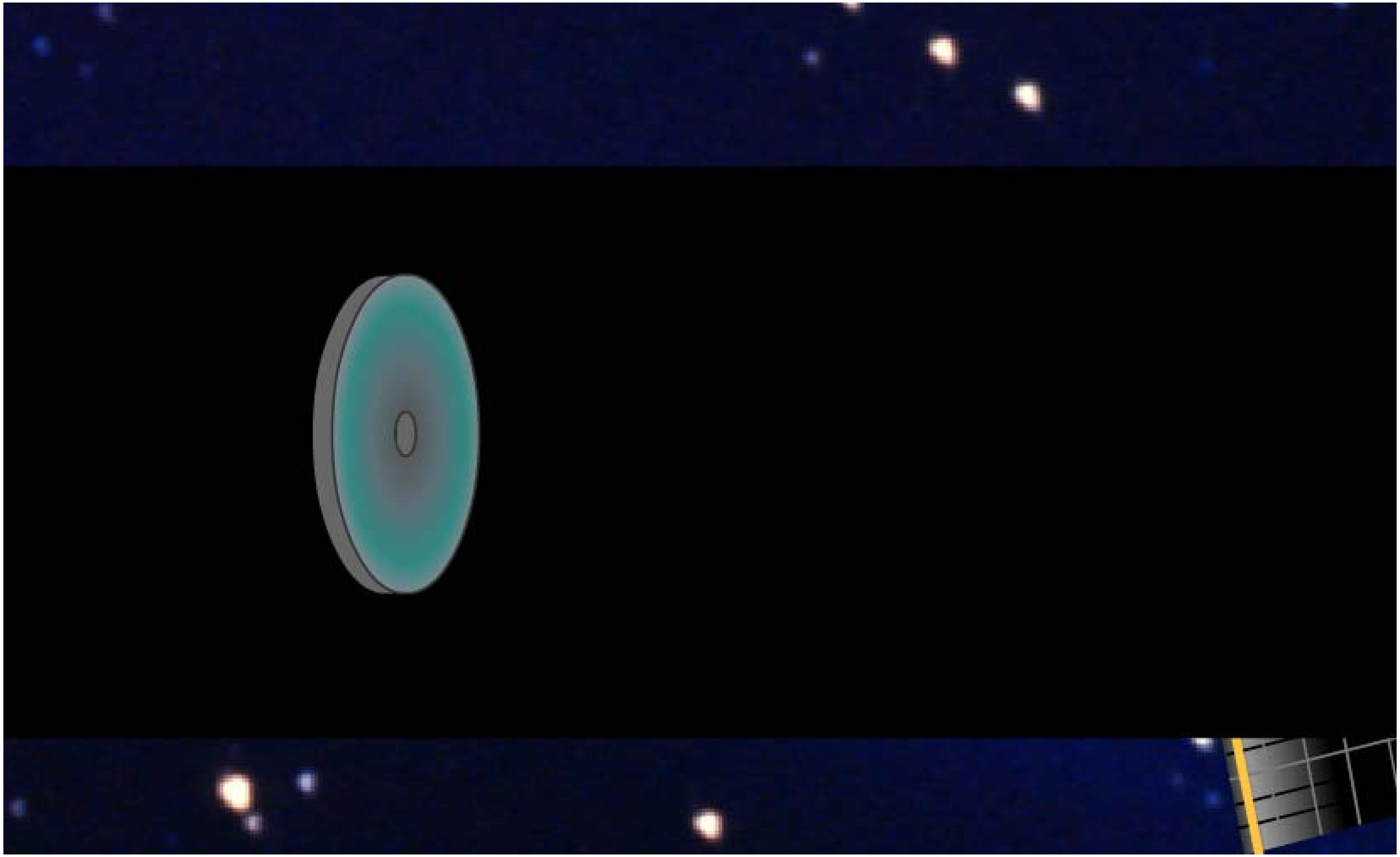
Finishing Advanced Mirrors – Answering the Challenge

- Aggressive reduction in areal density
- Simultaneous requirement for higher stiffness
  - Exotic geometries/materials
- Aggressive cost reduction
  - Main drivers for cost are lead time (touch time) and risk
- Address Scale-Up Issues
  - Large CAs for better contrast
  - Monoliths are expensive
  - Edge roll issues with segmented designs

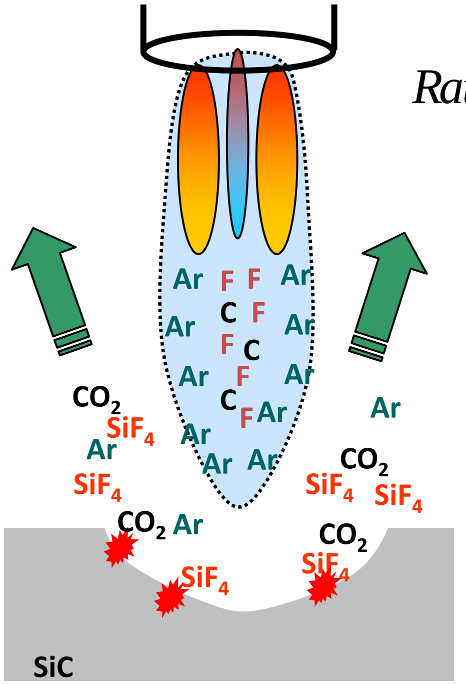


RAP™ Integrated Manufacturing Process (IMP)

RAP Processing of lightweight mirrors



The Chemistry of the Process



$$Rate = Ae^{-E_a/RT}$$

For SiO_2:

$$SiO_2 + CF_4 \rightarrow SiF_4 + CO_2$$

For silicon:

$$Si + CF_4 + O_2 \rightarrow SiF_4 + CO_2$$

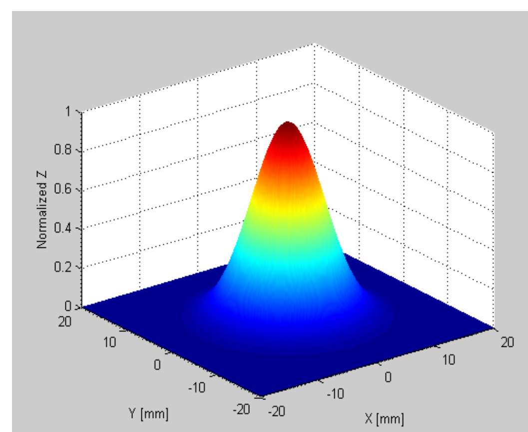
For SiC:

SiC + CF4 + O2 → SiF4 + 2CO

Reaction Products Must be Volatile

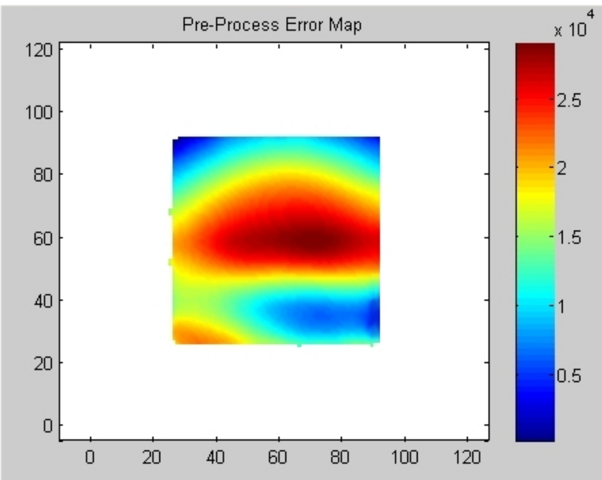
Other plasmas - other materials e.g. Ni, Be, Ti…

- Damage-free figuring @ atmospheric pressure
- Gaussian footprint for chemical figuring tool
  - Arrhenius rate reaction



Tool path algorithm

Error Map from Metrology



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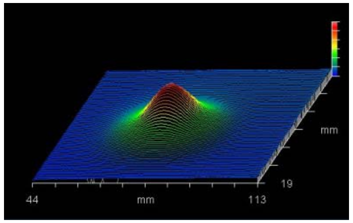
RAP tool shape



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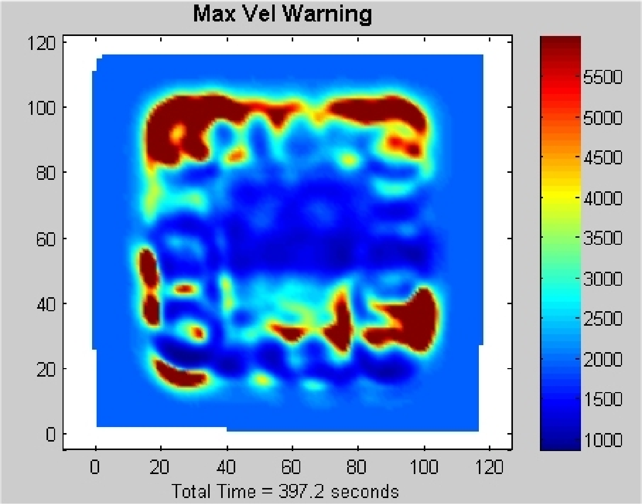
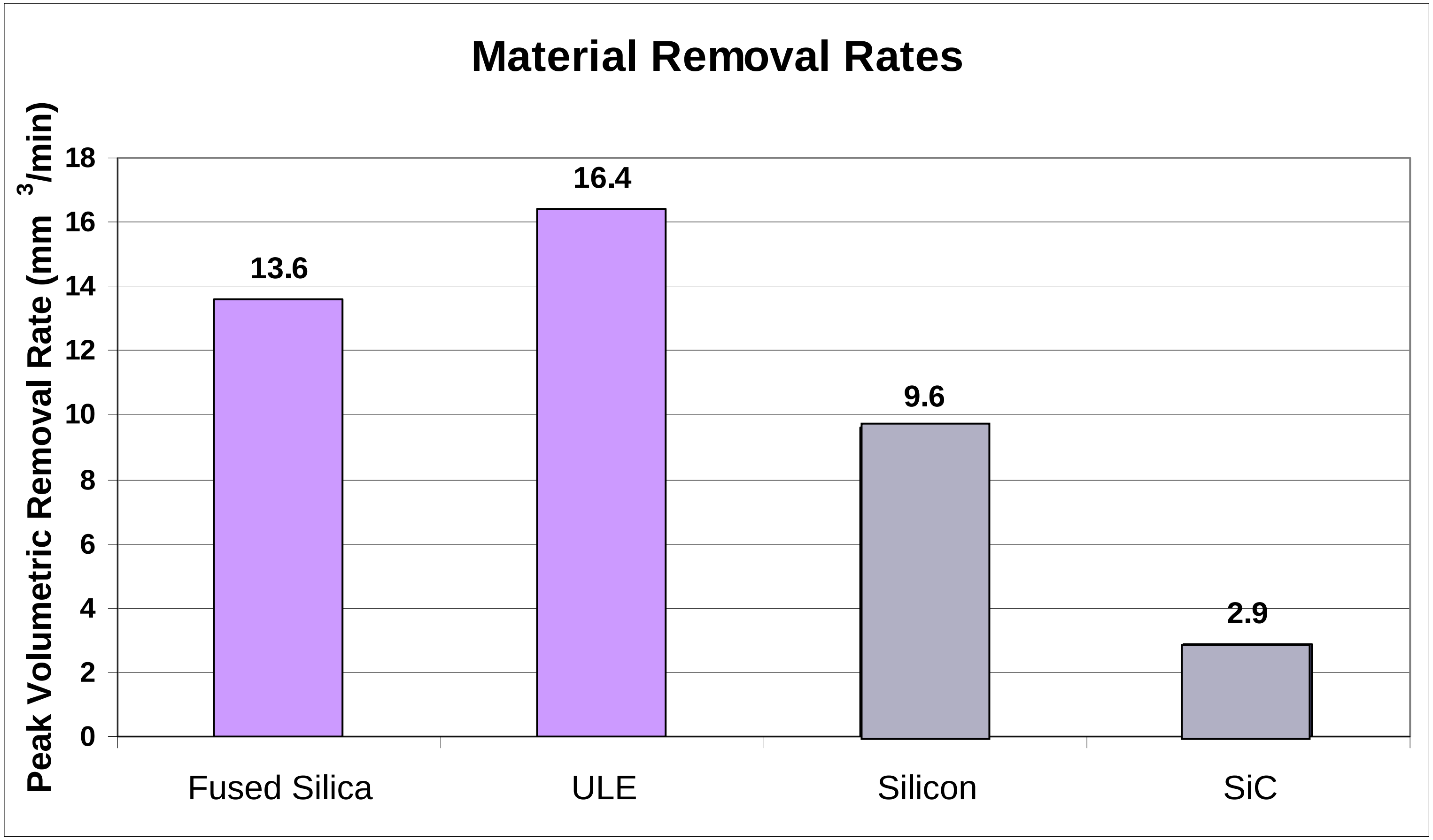


Calculated Velocity Map
(red means less dwell time)

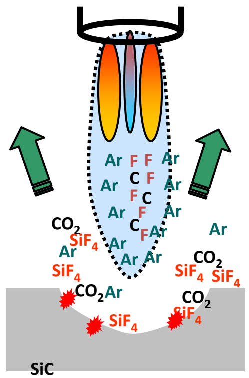
RAP Material Removal Rate



Rapid, Damage-Free Precision Surfaces - The IMP toolbox

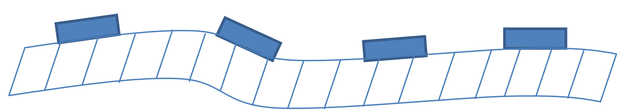
Chemical Figuring

- Non-contact
- Atmospheric Pressure
- Damage Mitigation
- Scalable
- Progressive roughening possible for polycrystalline substrates



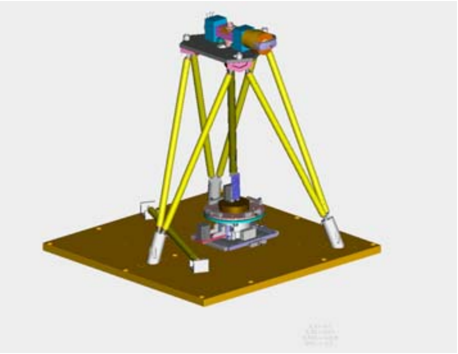
Conformal Buffing

- Pitch tiles to provide state of the art roughness
- Lap stiffness controlled to provide conformal behavior at low/mid spatial frequencies
- Low contact force

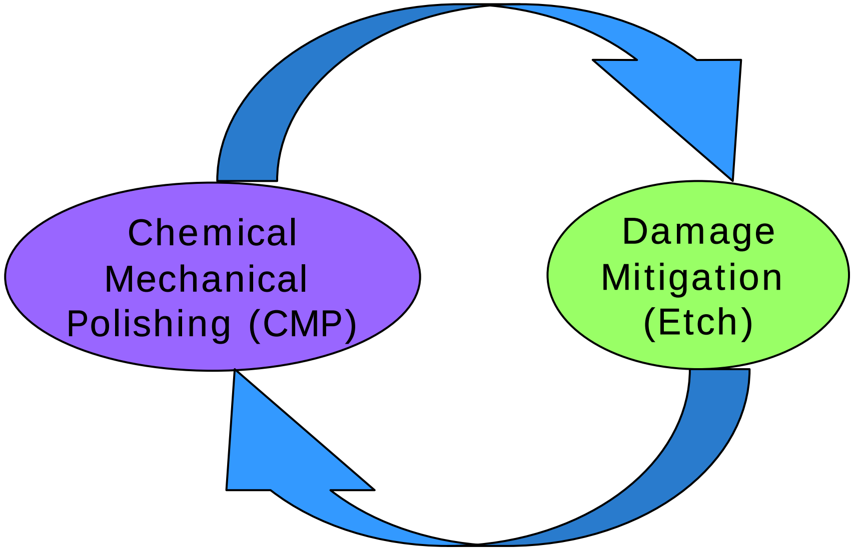


High Density Metrology

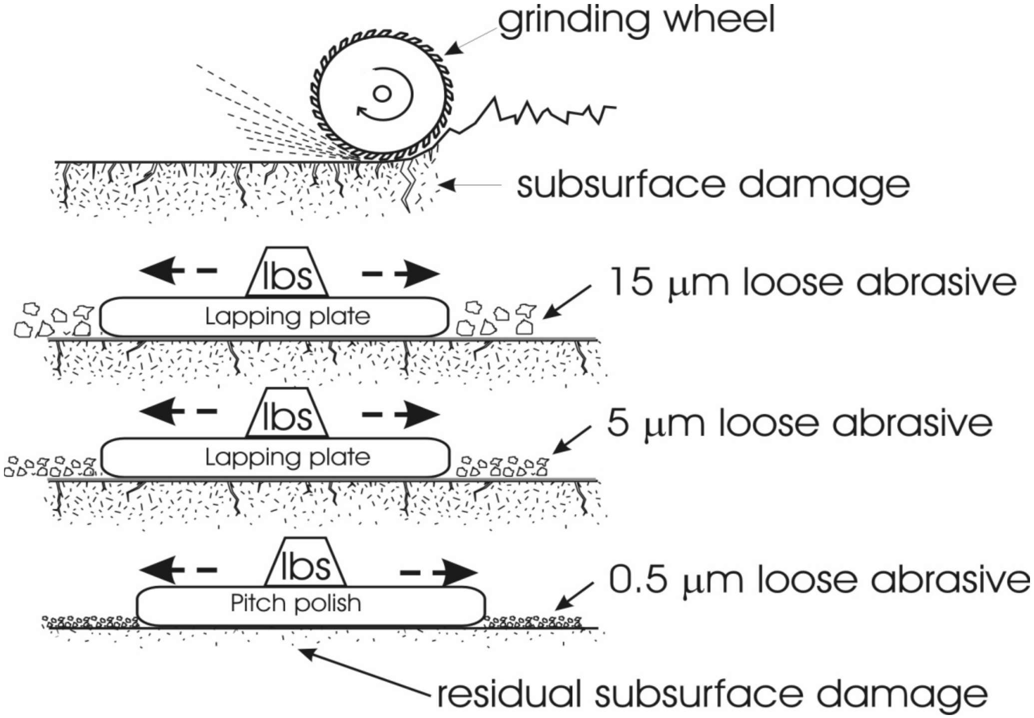
- Rapid collection of dense data
- Fast setup – reference to a mechanical sphere
- Seamless integration into tool path algorithm



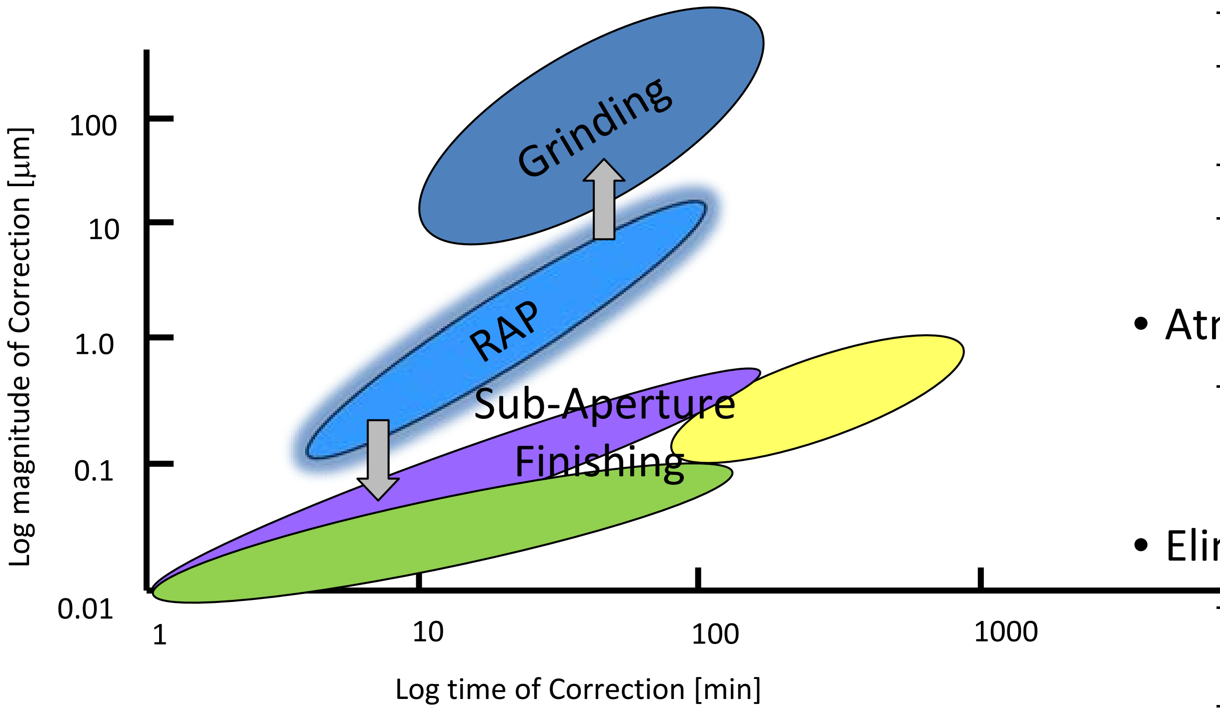
Mitigating subsurface damage during optics fabrication



Conventional

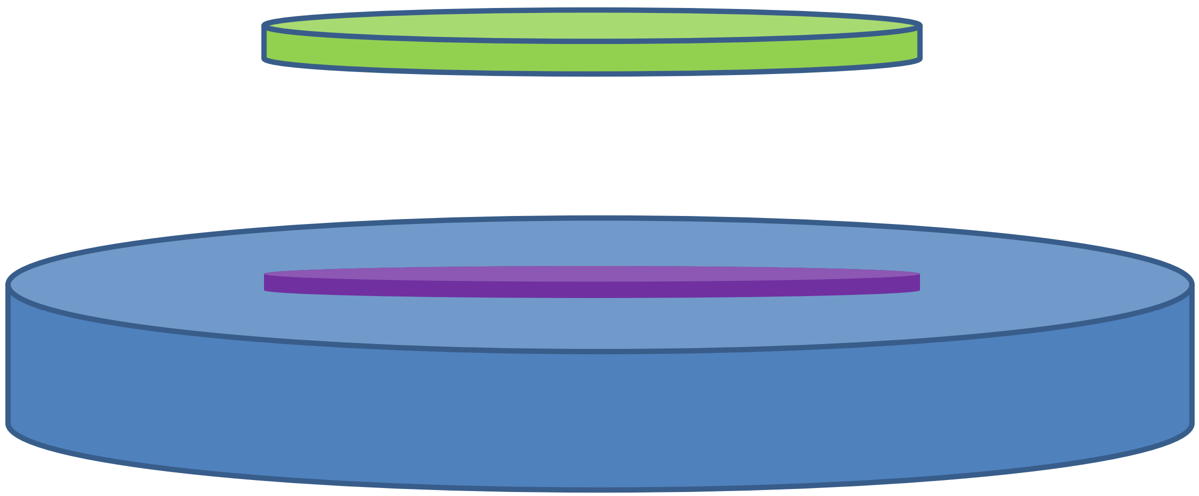


RAP Benefits



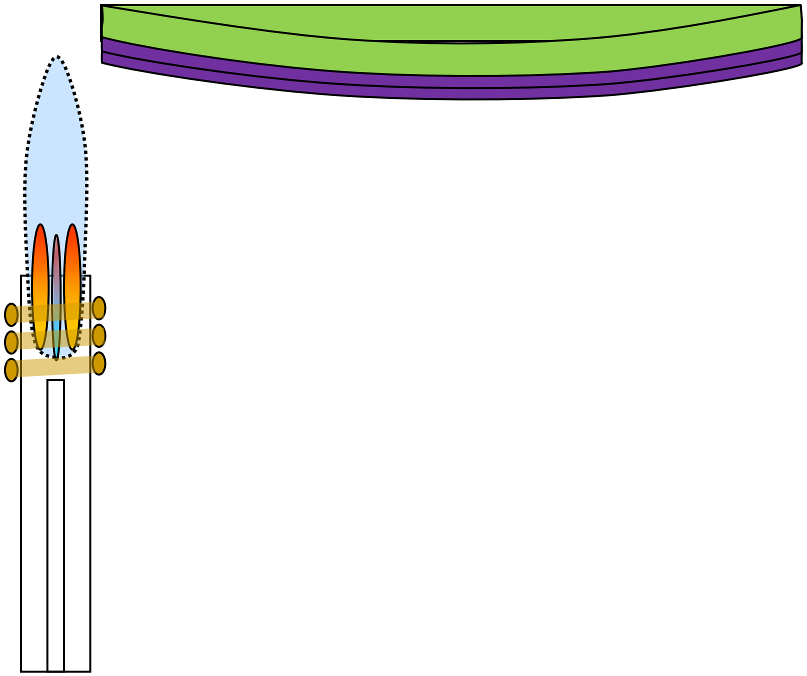
- Force-free Processing
  - No stress imparted
  - Deterministic convergence for high aspect ratio (low areal density) optics
  - No stiffness requirements on large tools
  - Allows the manufacturing of precise surfaces with low-cost imprecise tools
- Atmospheric Pressure Process
  - Vacuum Processing has scalability concerns, cycle time issues
    - Ion-beam milling
- Eliminates/Minimizes SSD
  - Contact Processing techniques impart SSD to surface
  - Reduction in tensile strength of optic
    - Chemical Mechanical Polishing
    - Single point diamond turning

Twyman Experiment Methodology

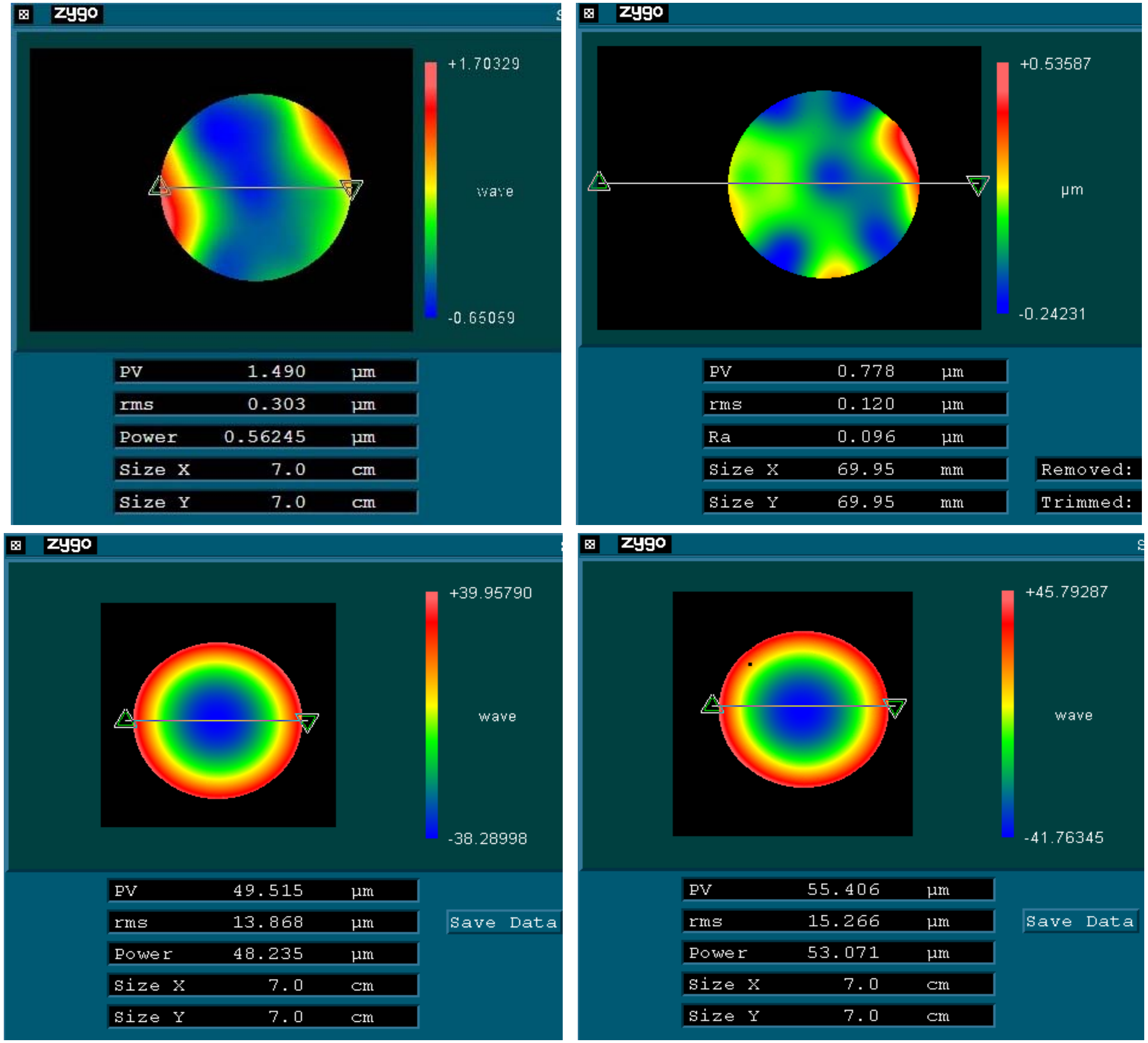


$$\sigma = \frac{4\,\delta\,E\,d^2}{3(1-\nu)\,t\,D^2}$$

σ = Tymann stress (unknown)
ν = Poisson's Ratio
E = Young's Modulus
t = Damage layer thickness (unknown)
d = Substrate thickness
D = Substrate Diameter
δ = Circular plate deflection (or Sag)



SSD from Milling

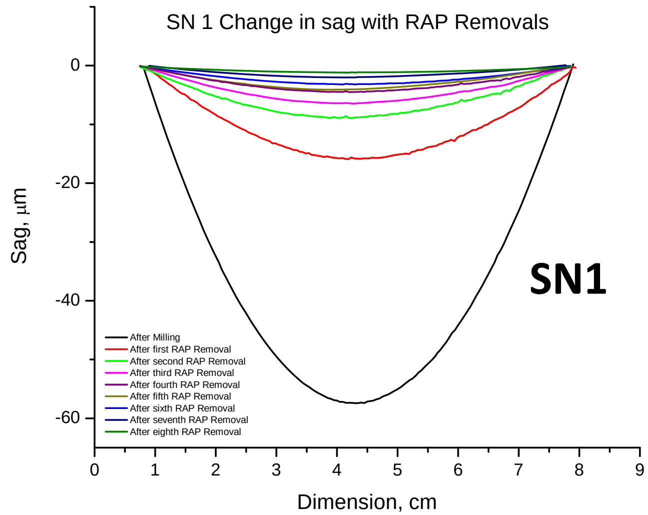


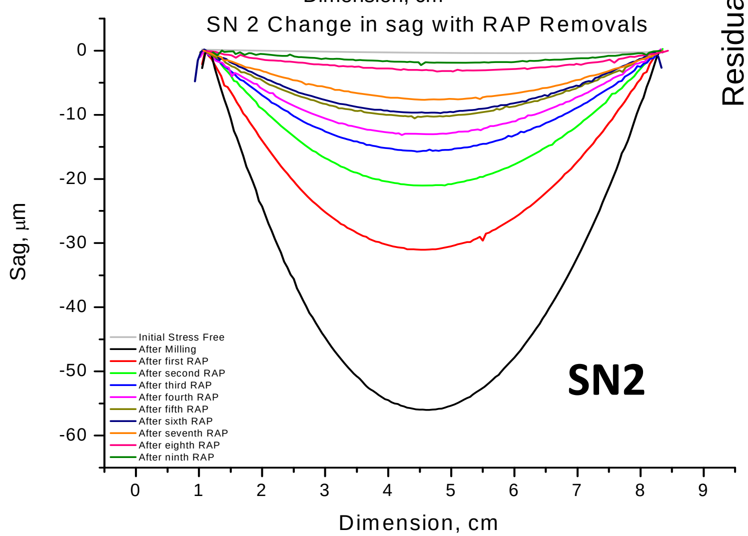
Before Milling

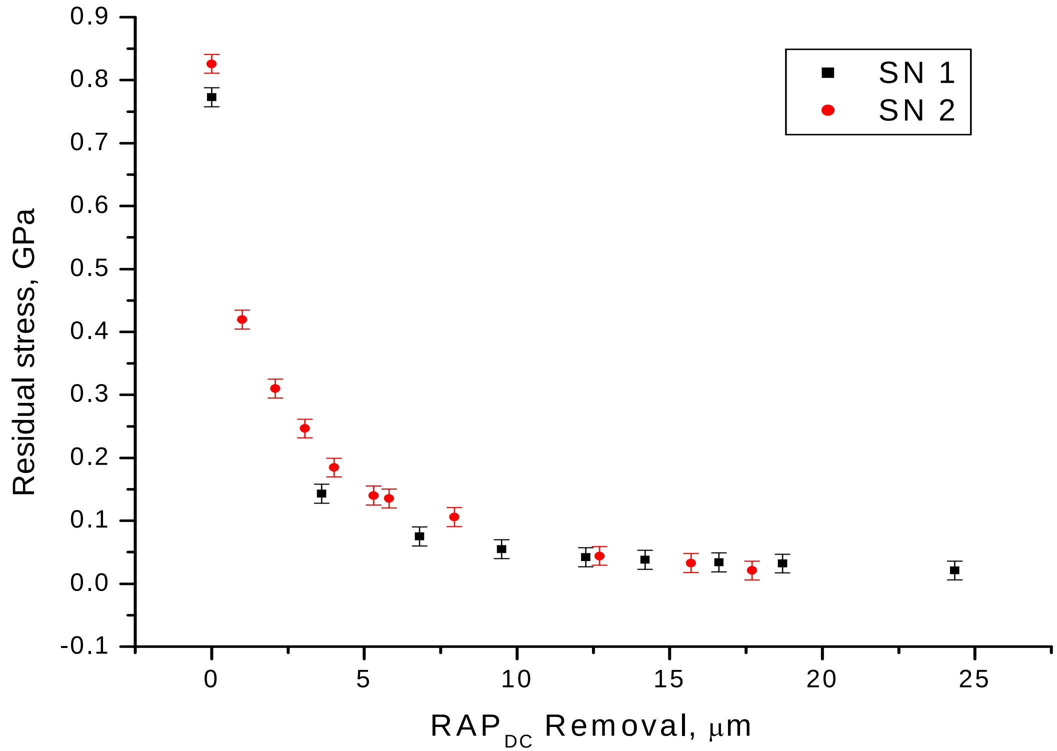
After Milling

SN1 SN2

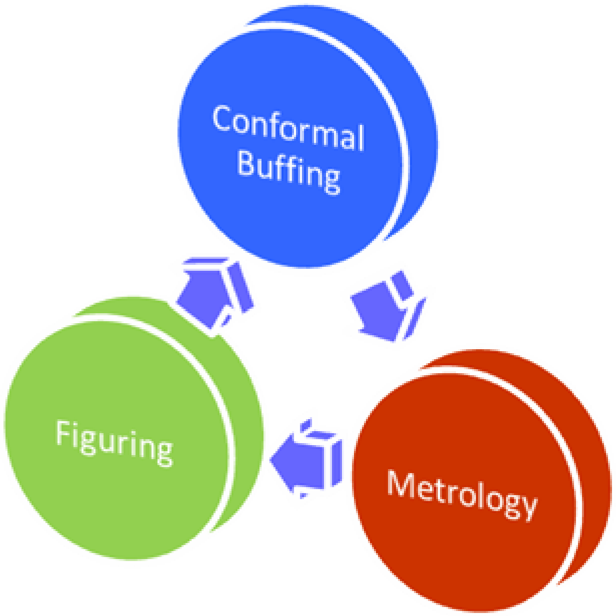
Stress reduction through RAP™

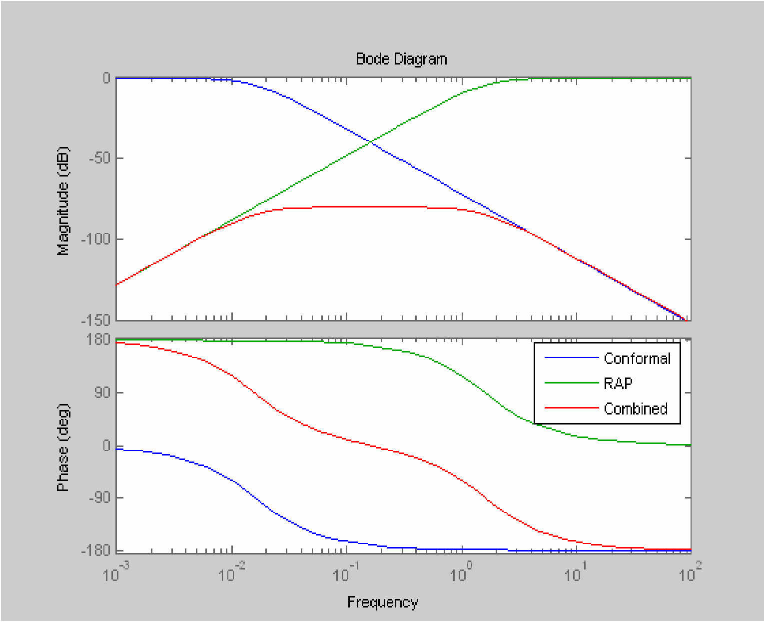






RAP IMP – Application to SiC



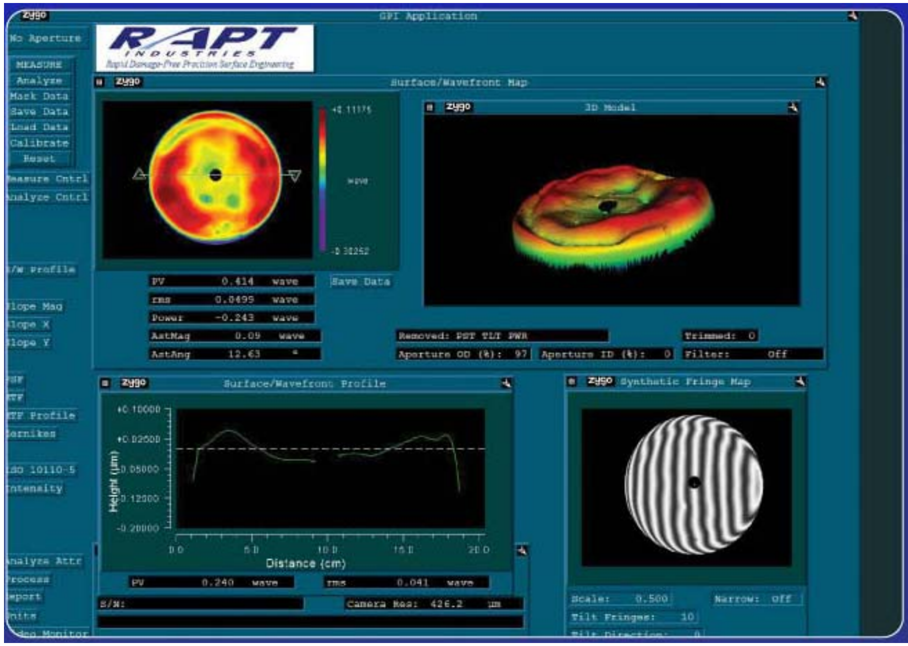


- High activation energy for SiC – thermal management during figuring critical
- Considerable knowhow to minimize edge-effects
- RAPT to address opportunity through manufacturing services out of PA
- Polycrystalline/multi-phase materials roughen up, iteration between figuring and buffing needed to obtain desired figure/roughness
- 150th wave RMS figure and 3 Angstroms RMS roughness achieved repeatably

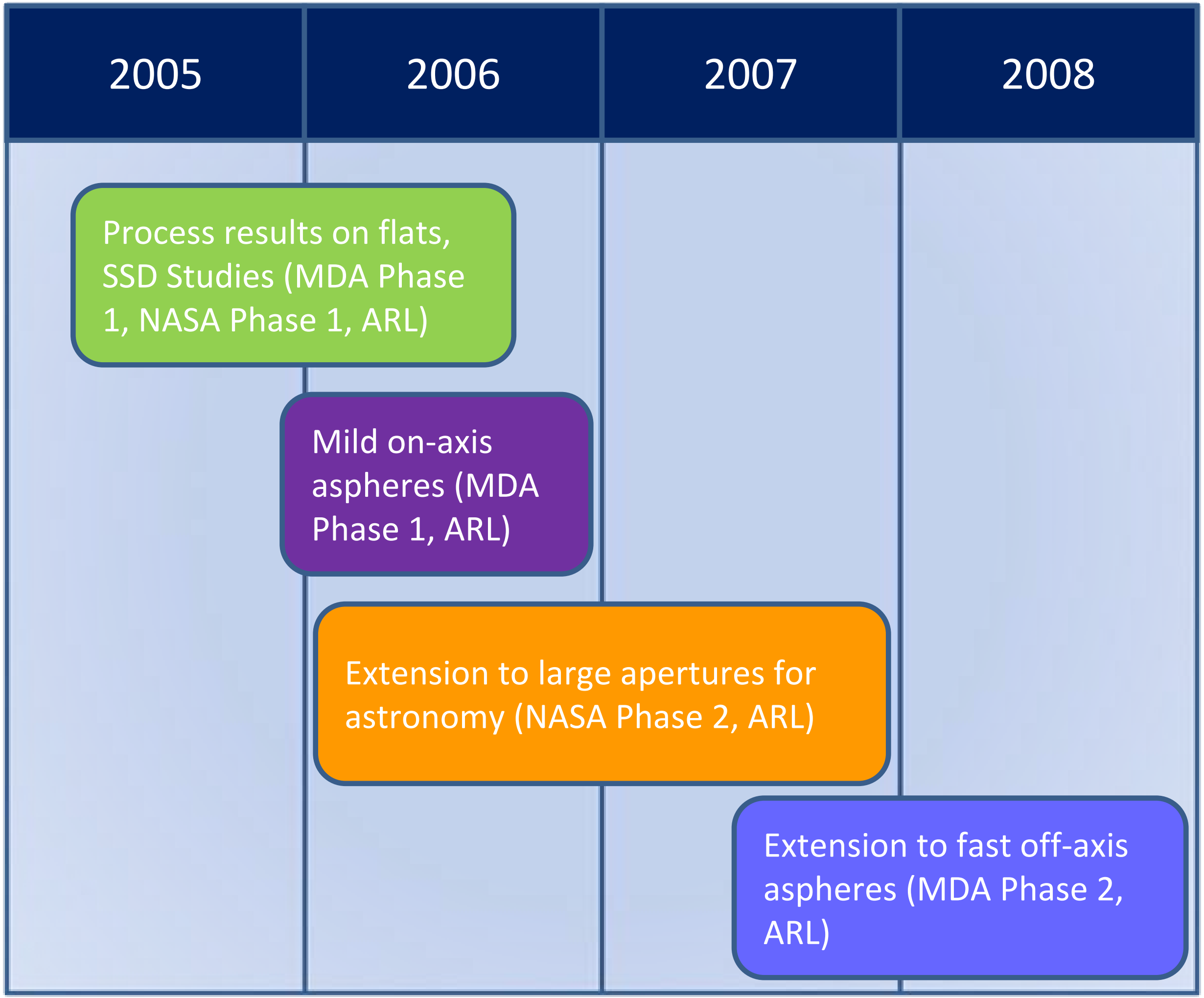
On-Axis SiC parabola for Ball Aerospace

- On-axis SiC f/2.25 parabola
- 200 mm clear aperture
- Finished to 0.050 λ RMS
- Roughness of 3.3A RMS

- Asphere figuring in 3 weeks
- Can achieve figure errors of 0.010 λ RMS



Our Programs



- W911NF-04-2-0001 – Army Research Laboratory

  COTR: Dr. Jane Adams
- NNM06AA11C – NASA Phase 2 SBIR – MSFC

  COTR: Mr. John West
- W9113M-07-C-0149 – MDA Phase 2 SBIR – AFRL

  COTR: Dr. Larry Matson

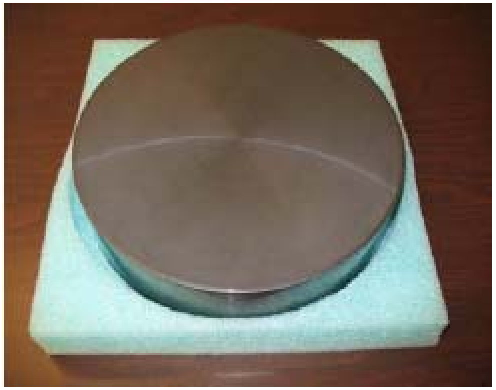
Gap in developing scalable thermal strategies – Needed for large SiC mirrors

Current Projects - ARL

- Army Research Lab
  - Multi-year project to develop RAP process for rapid production of SiC optics
  - Current year program primarily focused on equipment development
    - Third generation prototype RAP system design and build
    - Process characterization
    - Hardware/Software enhancement
      - Plasma process
      - Coarse metrology
      - Algorithms

Current Projects - NASA

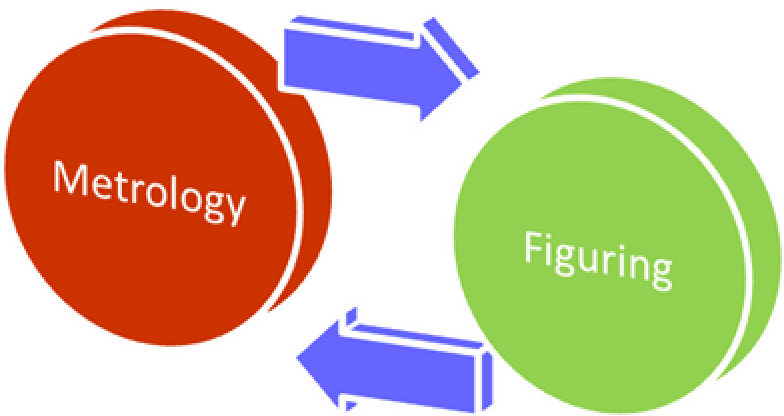
- NASA SBIR Phase II
  - Objective: To demonstrate IMP on powered SiC optics
  - Tasks:
    - Develop design for lightweight SiC optics
      - Comparable to JWST segments
    - Optimize process for powered mirrors
    - Produce 300mm aspheres (on-axis)
    - Study scale-up to 1 meter class mirrors

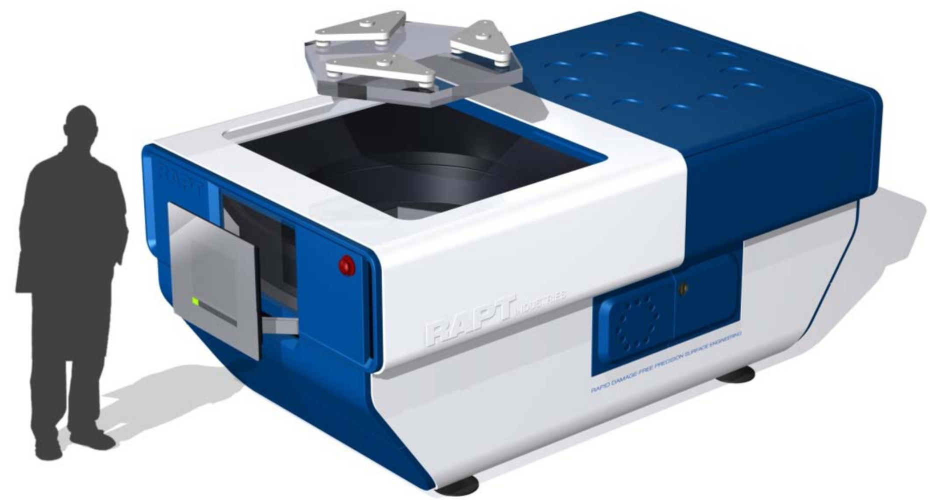


Current Projects - MDA

- MDA SBIR Phase II
  - Extend IMP to the production of fast, off-axis SiC aspheres
  - Target design: ~300mm diameter f/1 off-axis parabola
  - Development Tasks:
    - Apply RAP to steeply curved surfaces
    - Profilometry of fast off-axis aspheres
    - Demonstrate deterministic sub-aperture figuring processes

RAP IMP – Application to “Glass”





- Lower activation energy for “Glass” materials permits “cool” operation
- Fine, highly deterministic figuring runs at atmospheric pressure lead to very little change in surface roughness
- RAPT to address opportunity through the sale/lease of highly automated tools

Results on Glass/Glass-Ceramics

- Currently in preliminary stages of assessing RAP etching of various mirror substrate materials
  - Fused quartz extensively studied
  - Pyrex successfully aspherized
  - Figuring of ULE in progress
  - Preliminary results on Zerodur look promising
- For these materials, surface roughening during RAP is related to SSD
  - Well-prepared surfaces do not get significantly rougher with etching

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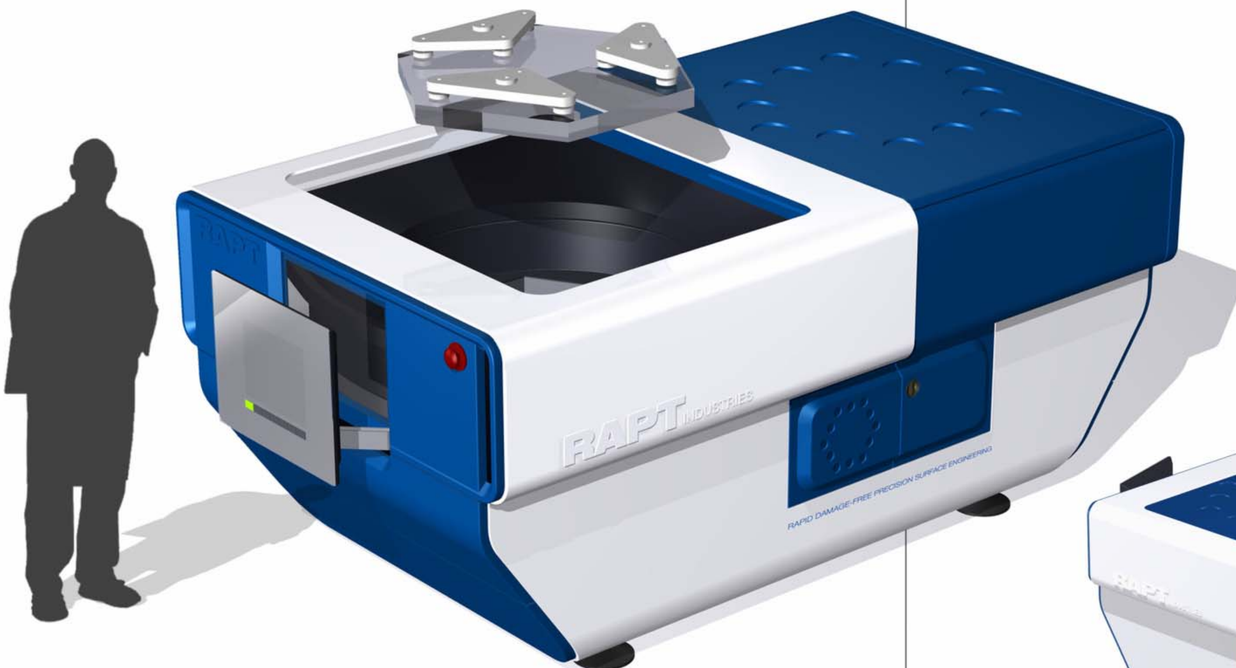
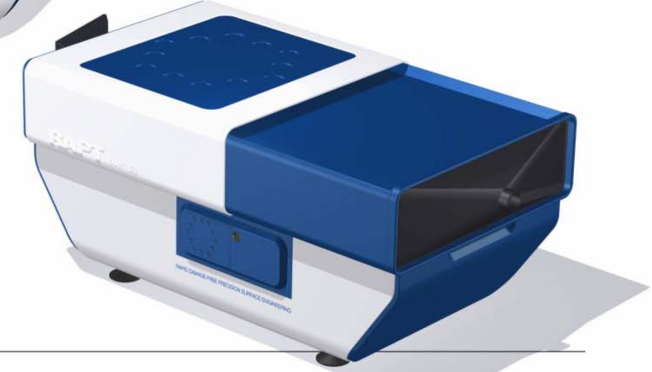
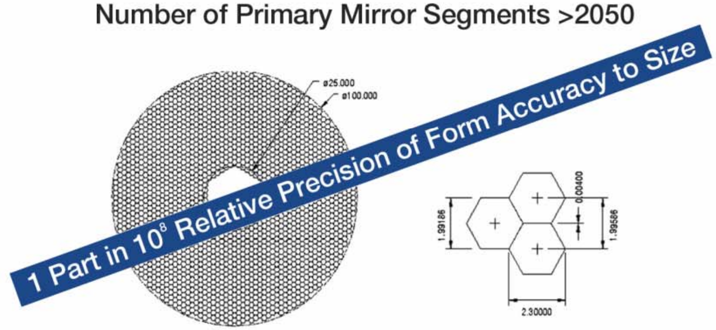




Large format "Reactive Atom Plasma (RAP™) Processing Machine"

>Meter class optics figuring
>Precision material removal, 10 nm to 10 micron
>Ability to work common optical materials
>Sub-surface damage mitigation
>Competitive material removal rates
>Non-contact processing at atmospheric pressure

Number of Primary Mirror Segments >2050



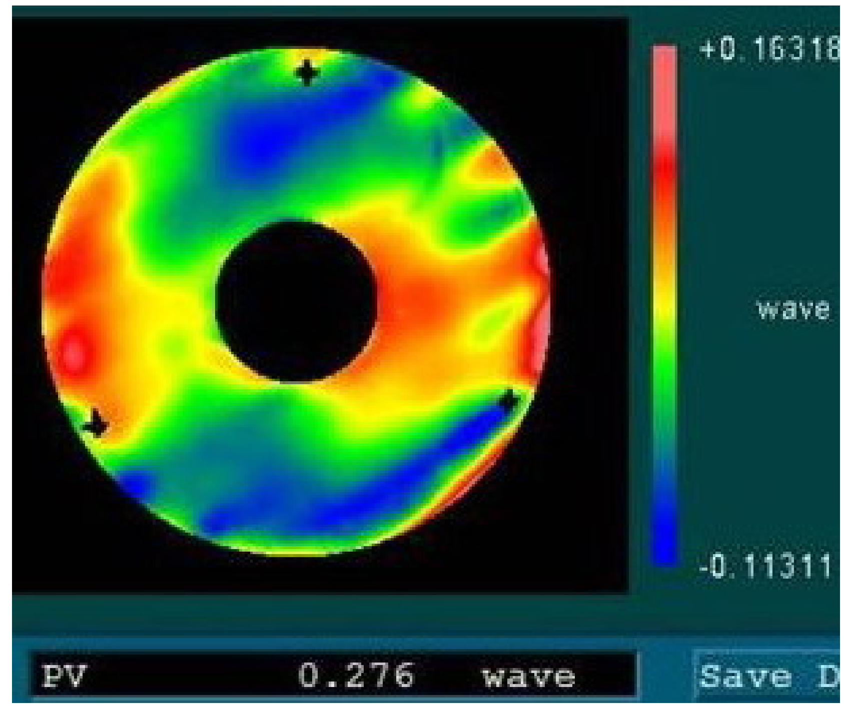
OWL Primary Mirror

Form Accuracy 25 nm
Roughness <1 nm

Developed in Collaboration with Cranfield UNIVERSITY

Conclusions

- RAP Processing is effective for damage-free shaping of SiC
- Integrated Manufacturing Process has been used to rapidly produce several aspheres
- Ongoing programs with ARL/NASA/MDA are providing advances in both process and equipment
- Production of fast, off-axis aspheres is coming
- Application of IMP to glass and glass-ceramic mirror materials is showing significant promise



8” lightweight SiC asphere (parabola, f/4) finished to 0.27 λ PV