Stress via Twyman Effect and Subsurface Damage in Polycrystalline Silicon Carbide

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Outline

- Motivation: Impact of Stress and Subsurface Damage in SiC Optics
- Description of Experiment
- Twyman Effect Overview
- Subsurface Damage (SSD) Background
- Techniques for Measuring SSD or Stress
- Results

Impact of SSD and Stress in SiC

- SiC of interest for space based optics
  - Stiff, light weight with high thermal conductivity and low CTE
- SiC is very hard; requires significant tool pressure during grinding
- Stress can adversely impact the figure at cryogenic temperatures
- SSD microcracking introduces scatter, reduces the strength which could lead to failure

Description of Experiment

- Stress in CVD SiC was compared for various processing conditions by measuring the deflection due to the Twyman Effect
- Comparisons were made for surfaces lapped with 3 µm diamond on a steel plate, 3 µm diamond polished on polyurethane pad, 1 µm diamond polished on a pad, chemically etched, and magnetorheologically finished (MRF).
- The depth of the subsurface damage (microcracks) was measured for the various processing steps using MRF Spot Technique

SiC Sample Preparation

- TREX CVC SiC 50.8mm dia. X ~1mm
- Coupons were wire sawn using 20-35 µm fixed abrasive diamond (resulting in 7 µm PV) followed by double side lapping and polishing (DSL/DSP) using sequentially finer abrasives

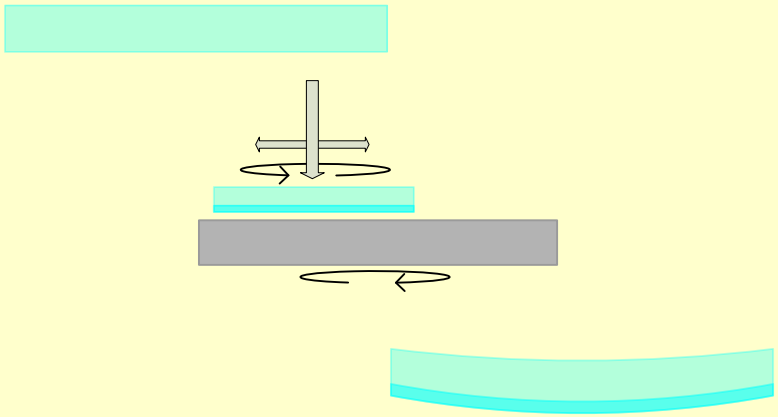
Diamond Abrasive Size	Material removed	Surface Roughness* (PV)
Lapping using steel plate		
6 µm	>15 µm	~300 nm
3 µm	~4 µm	~65 nm
Lapping using polyurethane pads		
3 µm	~4 µm	~50 nm

*Zygo NewView 5000, 20X Mirau, Min/Mod: 5.0, 660X880 µm Field of View

Twyman Effect

Twyman observed that a flat, high aspect ratio part double side polished will bow when one of the two surfaces is lapped as a result of the difference in stress between the two surfaces

- Lapping induces compressive stress causing the ground surface to be convex
- Stoney's Equation for thin films can be applied to calculate the stress if the damage layer thickness is known



$$\sigma = \frac{\frac{E}{1-\nu} h^2}{6Rt}$$

where h is the thickness, R is the resulting radius of curvature, and t is the thickness of the damaged layer

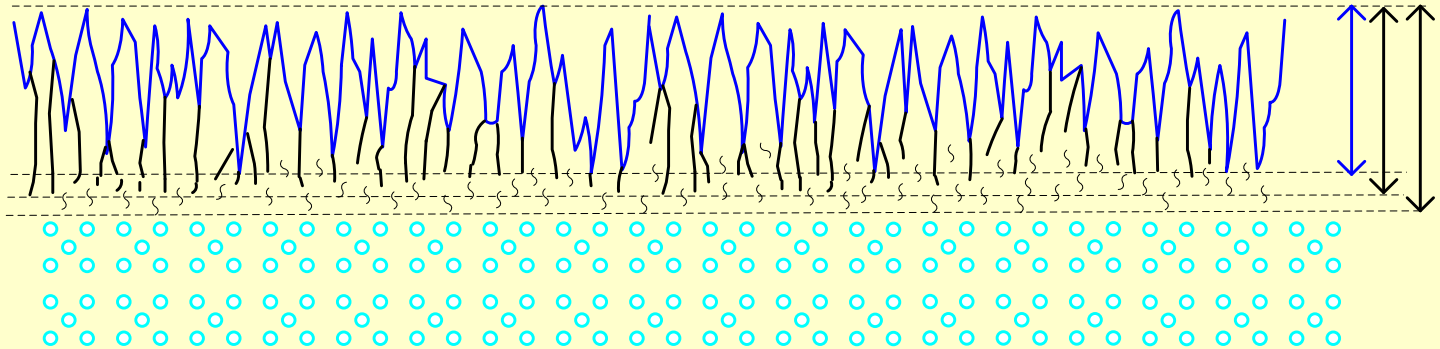
Wafer Polishing at QED using MRF

- MRF can remove uniform layers of material at specific removal depths without attention to pre-existing wafer bow
  - Diamond based MR Fluid was used
  - Parts held by vacuum using an acrylic backing plate
  - Each polishing step removed 100 nm
  - For each polishing step figure was measured with an interferometer to observe relaxation of the Twyman Effect
- 3 SiC wafers with different surfaces were polished and measured at QED

Subsurface Damage (SSD)

Subsurface Damage is the top layer of a bulk material that has discernable differences from the bulk as a results of surface processing

- SSD can contain microcracks from brittle material removal from grinding, and residual stress surrounding crack tips or from plastic deformation from ductile grinding or polishing



SSD Measuring Techniques

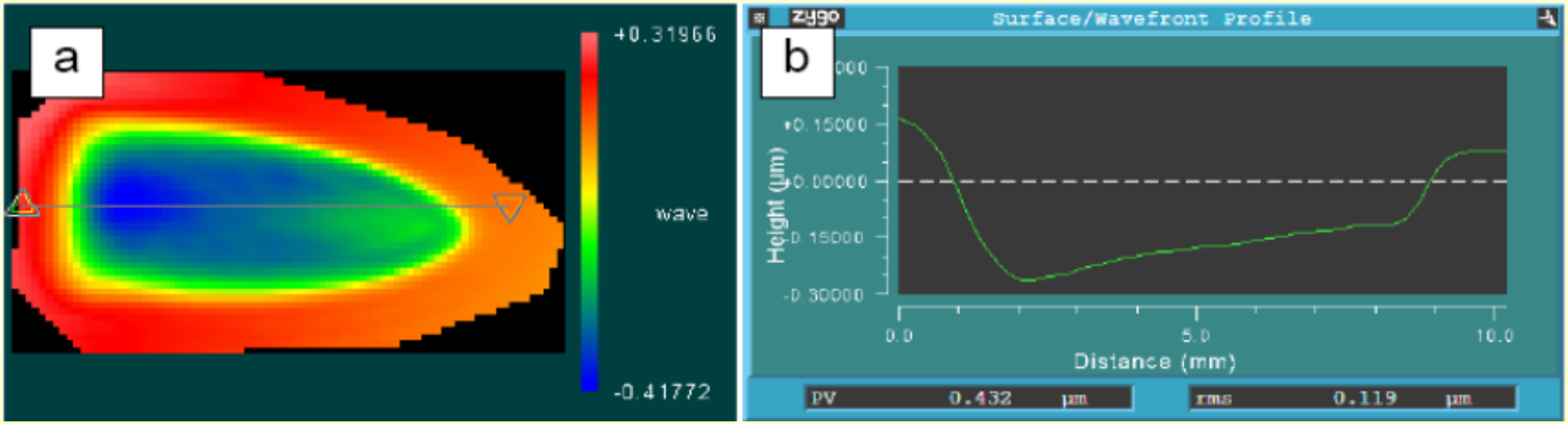
- Destructive: Taper polishing, Etching, Fracture Mechanics
- Non-Destructive Evaluation (NDE):X-ray diffraction, Scanning Acoustic Microscopy, Raman Spectroscopy, Birefringence, Photothermal Microscopy
  - Many of these techniques are qualitative, do not provide an accurate depth of SSD

SSD Measurements using MRF

- SSD measurements are taken using MRF spots to penetrate through SSD and calculate depth base on surface roughness and spot profile
  - MRF spots are taken at sequentially deeper depths until past the depth of SSD
  - Surface roughness measurements using a white light interferometer are made within the deepest region of the spot
  - Roughness decreases as the spot depth increases.
  - The depth of SSD is determined when the roughness levels and the spot is measured with an interferometer or profilometer

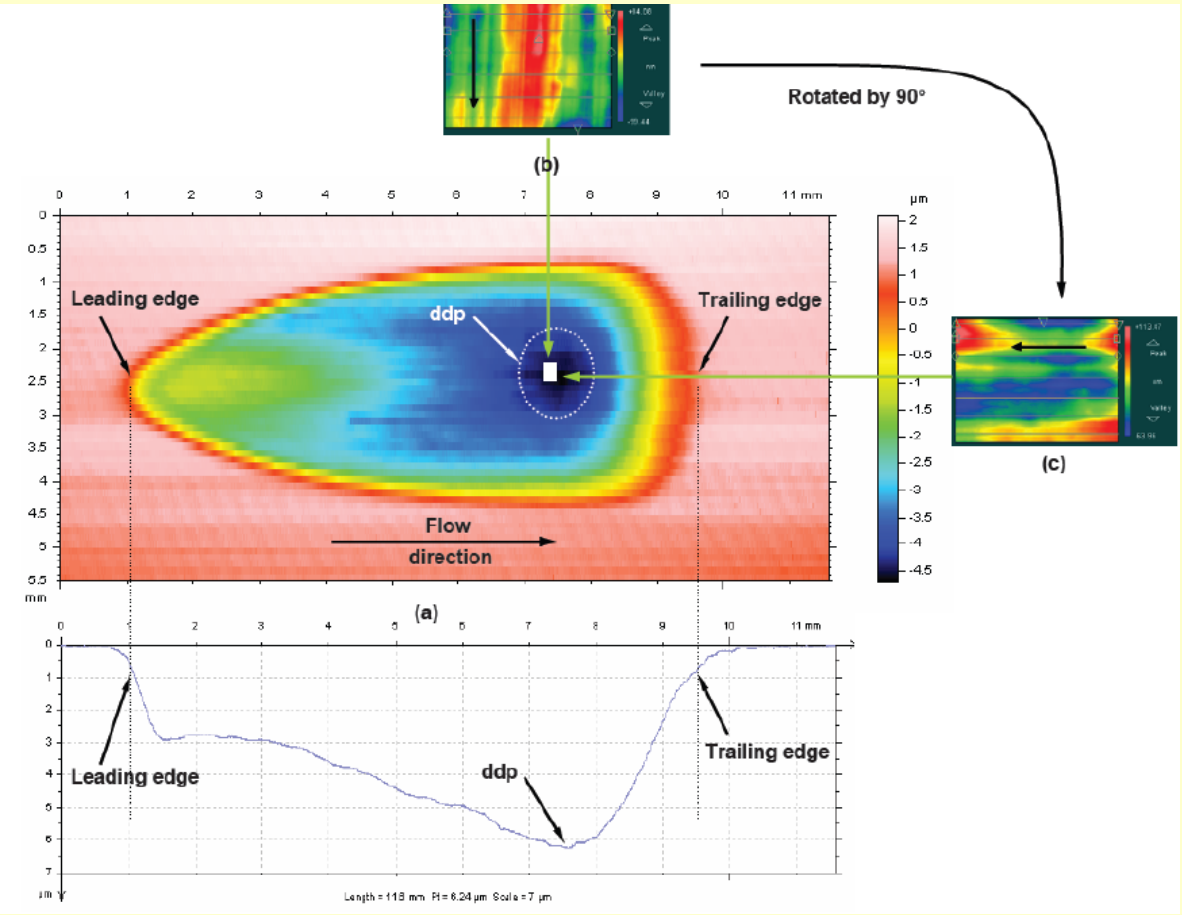
Measuring Spot Profiles

- Previous work shows a strong correlation between surface roughness and SSD-Good estimate of the required spot depth
- Applying this correlation spots with depths <0.5 µm can be profiled using an optical interferometer



MRF Spot Profile measured with an interferometer against a flat reference

Measuring Large Spots with Contact Profilometer



Spot profile from contact profilometer

- Interferometer scans within the deepest area of the spot are taken in a vertical and horizontal orientation to due to interferometer limitations
- Five line scans are collected within each spot, resulting in scan parallel and perpendicular to the fluid flow direction
- Roughness Data collected with NewView 5000, 20X Mirau Objective, 0.35X0.26, MinMod:3%

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