Affordable Pre-Finishing of SiC for Optical Applications

Mirror Technology Days 2011
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Presented by:
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Presentation Outline

• Introduction to Creare
• Background
• Innovation
• Phase I Results
• Phase II Update
• Summary
Corporate Background

- Founded in 1961
- Contract engineering R&D
  - Fluid dynamics and heat transfer
  - Cryogenics
  - Biomedical
  - Software and data systems
  - Sensors and controls
  - Advanced manufacturing
- Industrial and federal client base
- Technology commercialization
  - Licensing
  - Spin-off companies
  - Custom products
- Spinoff
  - 9 companies/2000 employees
  - Revenues $650 M/year
Advanced Manufacturing at Creare

- Focus on developing new technologies
- Process improvement
  - Cost
  - Quality
- Transition to industrial partners

**Laser-Assisted Machining**

**Indirect Cooling**

**Modeling and Simulation**

**Hybrid Processing for Ceramic Mirrors**

**On-Machine Inspection and Tool Path Correction**
Silicon Carbide

- Excellent candidate to replace beryllium in lightweight optics
- Eliminates toxicity concerns
- Lightweight, thermally stable
- Cost-effective manufacturing remains a challenge
### Overall Manufacturing Process

![Overall Manufacturing Process Diagram]

<table>
<thead>
<tr>
<th></th>
<th>Sintered Part</th>
<th>Pre-Finish</th>
<th>Optical Finish</th>
</tr>
</thead>
<tbody>
<tr>
<td>$R_a$</td>
<td>Moderate (~2 μm)</td>
<td>Low (~25 nm)</td>
<td>Very Low (~5 nm)</td>
</tr>
<tr>
<td>Accuracy</td>
<td>± 25 μm</td>
<td>± 100 nm</td>
<td>± 10 nm</td>
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<tr>
<td>MRR</td>
<td>N/A</td>
<td>High/Low</td>
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<tr>
<td>Process</td>
<td>Single Step</td>
<td>Multiple Steps</td>
<td>Single Step</td>
</tr>
<tr>
<td>Cost</td>
<td>$$</td>
<td>$$ $$ $$$</td>
<td>$$</td>
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</table>

#### High MRR Step
- Rapid removal
- Minimize SSD
- Accuracy ± 1 μm
- $R_a$ ~200 nm

#### Low MRR Step
- Minimal to no SSD
- Accuracy ± 100 nm
- $R_a$ ~25 nm

#### Transition
- From High MRR to Low MRR
Our Hybrid Machining Approach

- Use single-point diamond turning (SPDT)
- High MRR process: spin-turning
- Low MRR process: ductile-regime machining (DRM)
Program Overview

**Phase I SBIR**
- Basic Feasibility Testing
  - Functionality
  - Cost reduction
  - Operational constraints

**Phase II SBIR**
- Prototype Development
  - Retro-fit system
  - Control system development
  - Evaluate and optimize
  - Testing and scale-up
  - Demonstration

**Phase II&III**
- Commercialization and Transition

**Hybrid Mach. Proto.**

**AMETEK/Precitech**

**A Suite of Commercial Products**
Phase I Results

• Demonstrated feasibility of low MRR DRM on CVD SiC
  – Successfully machined material to near-optical quality

• Demonstrated cost savings
  – Completed detailed cost analysis
  – Showed that other options are as much as 85% higher cost

• Developed a plan to scale up
  – Developed the high MRR aspect of the hybrid approach
  – Both based on SPDT
  – Sufficient to machine optics for NASA
Phase I Technical Achievements

**Setup for Low MRR Tests**

- Laser Head
- Diamond Tool
- Load Cell

**Mirror-Like Surface Produced in CVD SiC**

**Tool Wear After ~100 Cuts**
Phase II Technical Objectives

• Optimize the hybrid machining process
  – Further develop high MRR process
  – Refine low MRR process

• Evaluate the performance
  – Coupled effects
  – Surface quality, part strength
  – Cost savings
  – Scale-up to larger geometries

• Demonstrate our approach
  – Machine a representative mirror (~254 mm diameter) from Trex CVD SiC and deliver to NASA
Develop High MRR Process

- Spin turner integration
- Rotating at 1 Hz with an encoded servo-motor
- Developed mounting hardware

LABVIEW GUI

- Custom LABVIEW® GUI for data acquisition and system control
- Spin turner motor control
- Camera positioning, image acquisition, analysis
- Acoustic emissions data
Tool Wear Measurement

**Optical**
- Integrated onto precision lathe
- Prosilica GC1600 camera
- 0.9 µm resolution
- Controlled by MATLAB® GUI to photograph multiple locations after each cut

**SEM**
- Thin carbon coating layer on tool prevents charge buildup
- Remove carbon coating from cutting edge
- Several measurements around cutting edge

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[Image: Spin turner cutting edge]

[Image: SEM image with labels: Cutting Edge, Carbon Coating (Flank Face), Diamond Surface, Carbon Coating (Rake Face), 10 µm]
Shakedown Testing

- Single crystal silicon optics samples
- 38 mm dia. x 3 mm thick
- Four optics for each condition

<table>
<thead>
<tr>
<th>Cutting Condition</th>
<th>Depth of Cut (μm)</th>
<th>Feed Rate (μm)</th>
<th>Undeformed Chip Thickness (μm)</th>
<th>Total Cutting Depth(μm)</th>
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<td>A</td>
<td>3</td>
<td>3</td>
<td>0.25</td>
<td>36</td>
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<tr>
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<td>6</td>
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<tr>
<td>D (uncut)</td>
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Sample Disks Appearance

Sample Disks
• Small depth of cut cases (A, B) show clear evidence of ductile to brittle transition depending on cutting orientation

Modulus of Rupture Bars
• 35 x 4 x 3 mm thick
• 2 bars per sample (32 total)
• Profilometry before strength testing

MOR Bars undergo 4-point bending failure test
Results-Silicon

Surface Roughness

- Surface roughness generally increases with chip thickness.

Flexure Strength

- General trend of decreasing strength with increasing surface roughness.
- Surface roughness alone insufficient to predict strength from current data.

0.7 μm optimal undeformed chip thickness.
Summary of Technical Status

- Completed full integration and baseline testing of spin turner and tool measurement system
- Completed spin-turning tests of silicon and completed subsequent strength measurements
- Moving on to silicon carbide now
  - Repeat spin turning/strength tests
  - Refine single-point turning process
  - Optimize
  - Fabricate larger SiC mirror as final deliverable

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<th>Depth of Cut (µm)</th>
<th>Feed Rate (µm/rev)</th>
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<th>Total Number of Cuts</th>
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Questions