Novel Material Processing Using Ultrafast Laser Technology
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Introduction

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3. Anamorphic Grating Experimental Setup
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Motivation

1. Avoids the need for substrate dopants required for UV holographic gratings (or FBGs).
2. Reduces or eliminates NL self-focusing in bulk material due to very small NA and from the anamorphic/elliptical beam. References: Yariv, Appl. Phys.; Mazar, SPIE Vol. 4633.
3. Faster Micromachining Process
4. Ease of Manufacturing
5. Accurate/Predictable Structures since no self-focusing or filamentation occurring.

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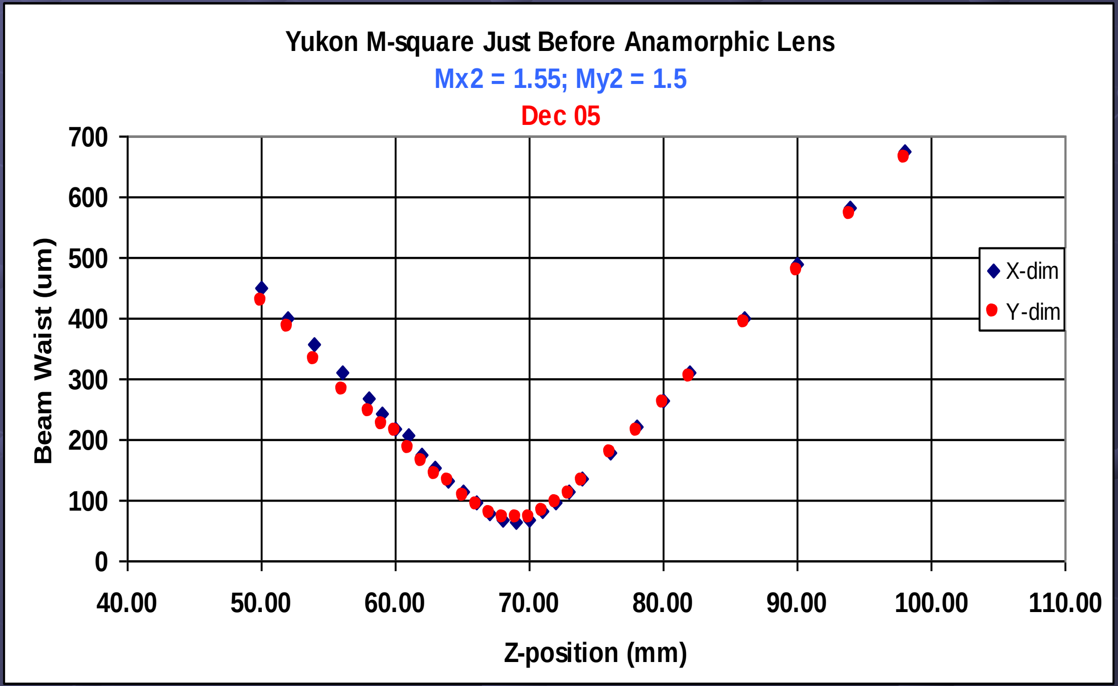
Beam Parameters: M^2

- The M2 of the femtosecond beam before the anamorphic lens.
- The data and M2 result was done using Spiricon M2 software.
- The results show a M2x = 1.55 and M2y = 1.5, which is also the Clark-MXR, Inc. specification, thus the laser was performing fairly well for these experiments.



- Pulse Width
- Raw Beam Profile
- Spectrum
- Energy JM Measurement

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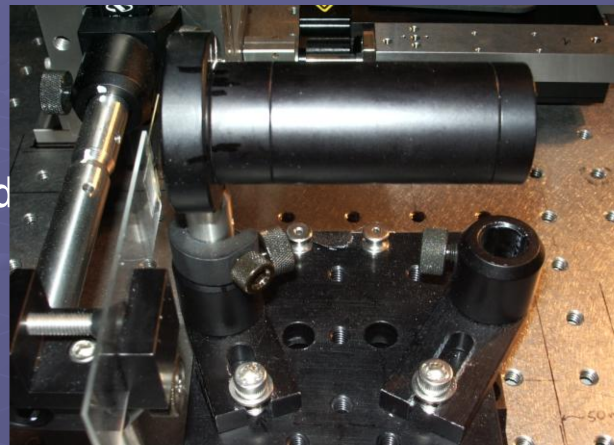
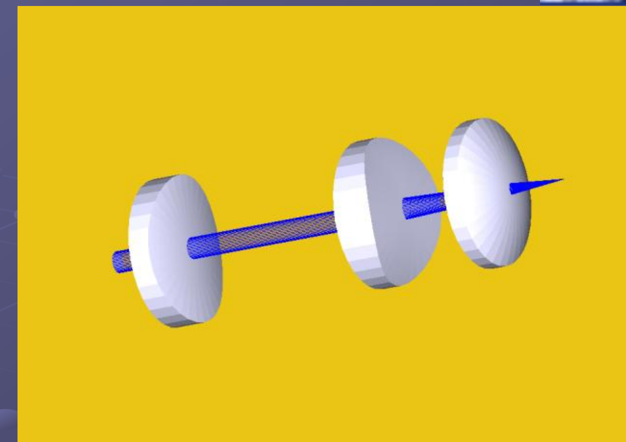
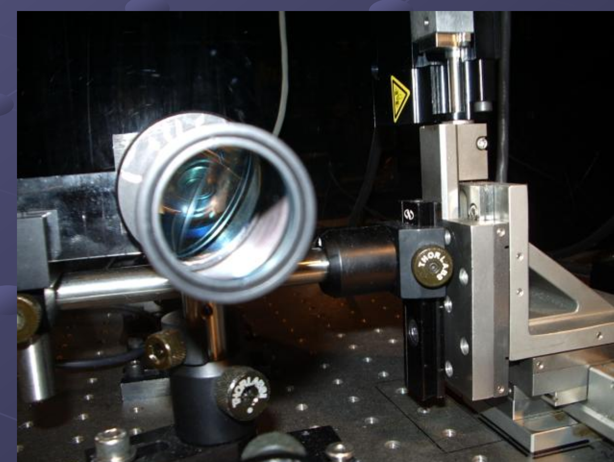
Anamorphic Lens Design:

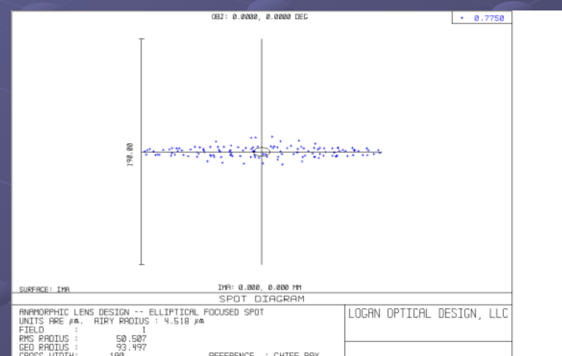


- Zemax solid model of the anamorphic design.
- Reduces self-focusing and filamentation in bulk material.
- Ease and speed of micromachining.

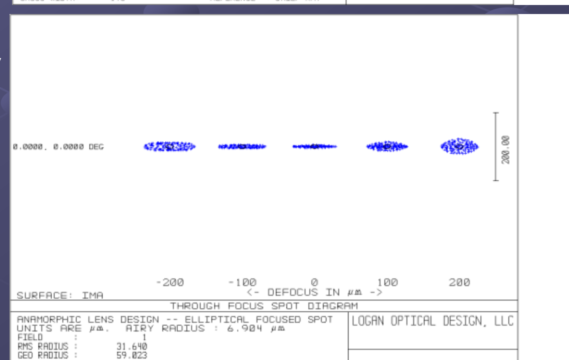




- Zemax Spot Diagram:
  - Shows ray distribution of 150um x 2.5um



- Zemax Through Spot Diagram:
  - Shows the morphology of the ray distribution of ± 200um through focus.



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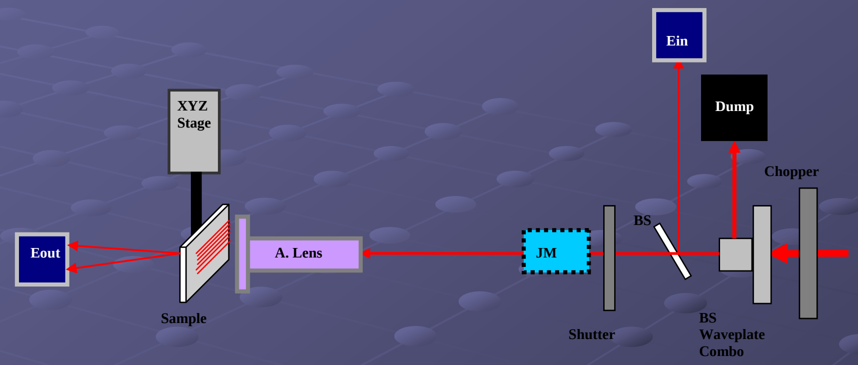
Anamorphic Lens Characterization:

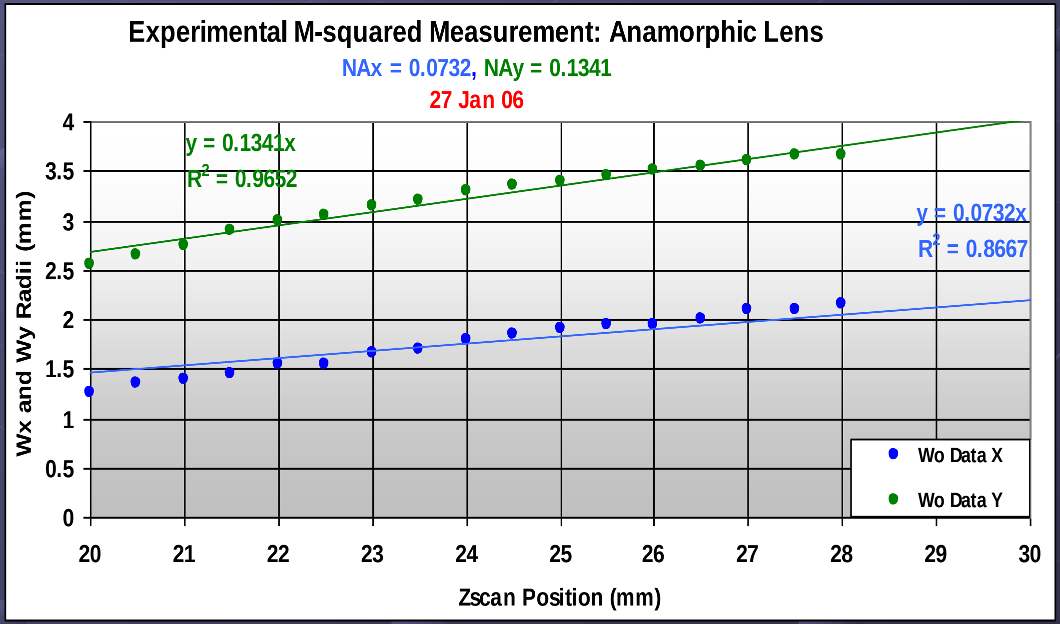
- The NA was theoretically calculated using Zemax.

- Then the NA was experimentally measured.



$$NA = \frac{D}{2f} = n\sin(\theta) = \sqrt{n_1^2 - n_2^2},$$

- The results show:
  - •NA Zemax Theory:
    - •NAx = 0.0774
    - •Nay = 0.1289
  - •NA Experimental:
    - •NAx = 0.0732
    - •Nay = 0.1341



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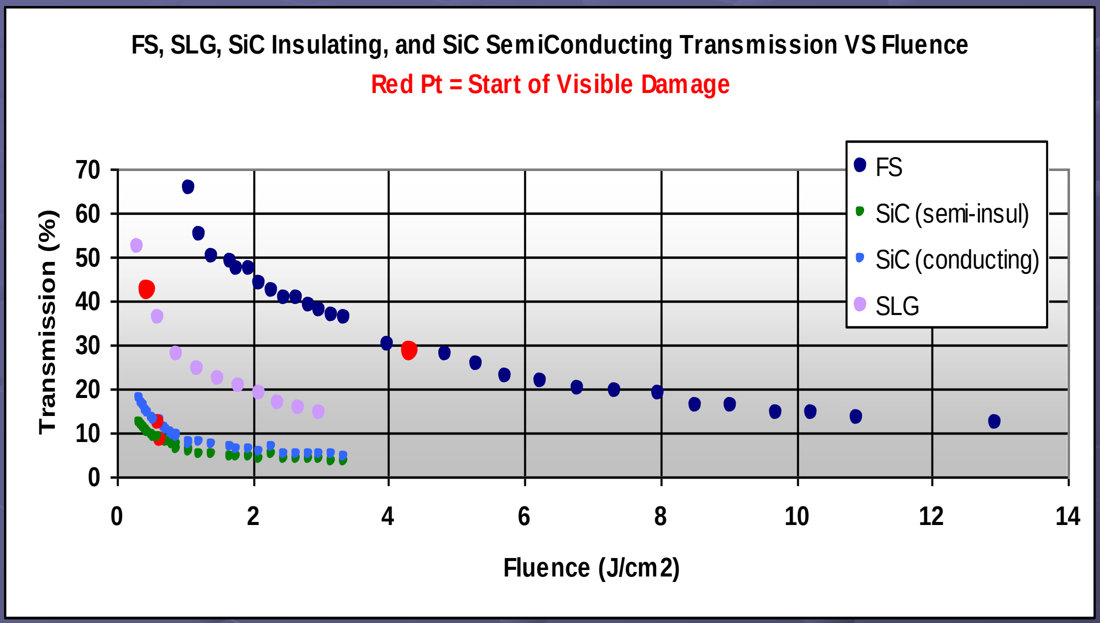
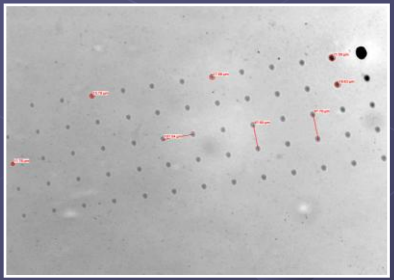
Ultrafast Damage Threshold in SiC



- Fused silica sample tested as a reference (threshold comparable with literature).
- Non-linear absorption causes initial drop in transmission.
- Visible physical damage typically starts at ~20-30% transmission. Observed using visible microscope.
- SiC surface imperfections (scratches) and sample clarity cause threshold variations

SiC Physical Damage:

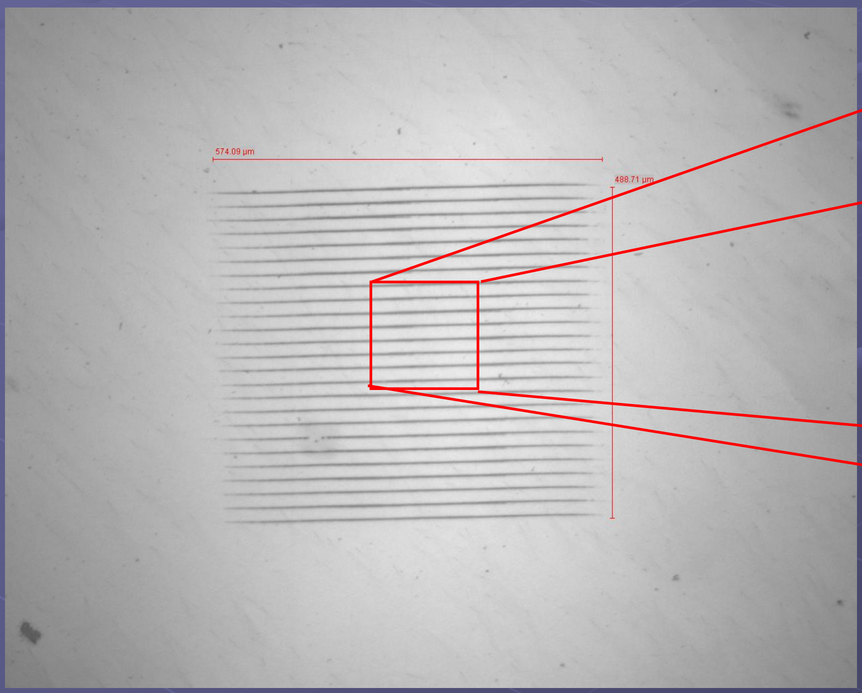


16 Visible Damage Rows

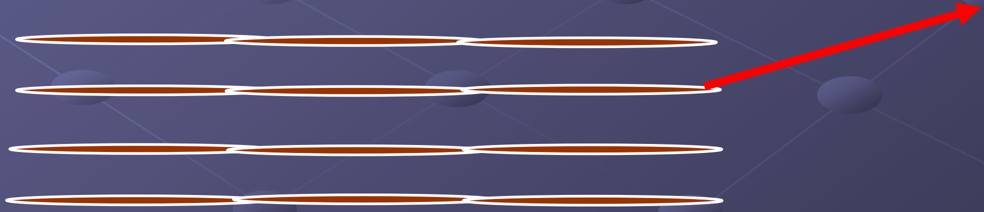
- Single Shot Damage Threshold Comparison:
  - Fused Silica ~4 J/cm^2
  - SiC ~0.7 J/cm^2
  - SLG ~ 0.4 J/cm^2

SiC Semi-Insulating Grating: Pictures

- **10X: 580um X 490um**



- **50X: d = 20um; Width = 2.5um**



Grating Morphology:

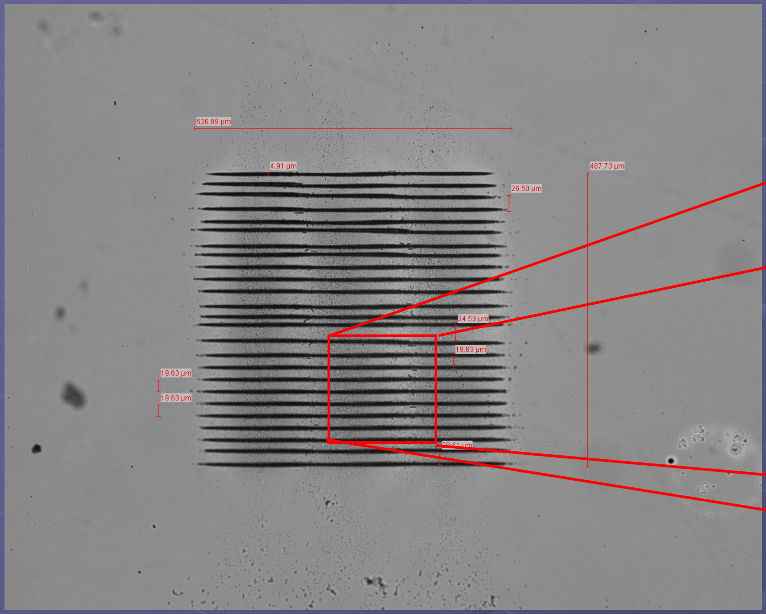
•3-4 anamorphic beams in a row.

•Each anamorphic line ~ 150um x 2.5um.

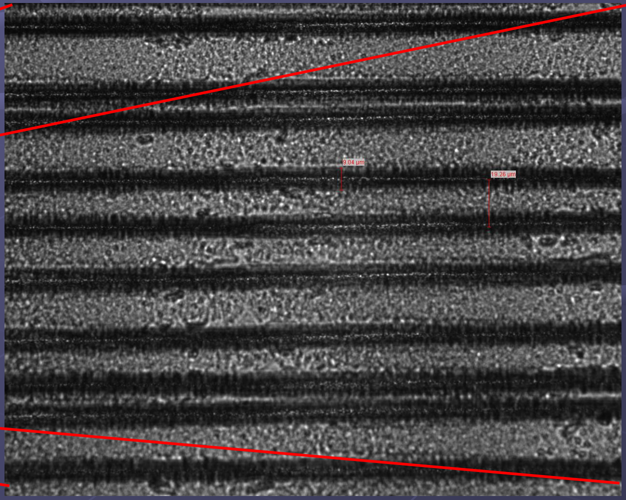
•25 Rows resulting in 20um spacing.

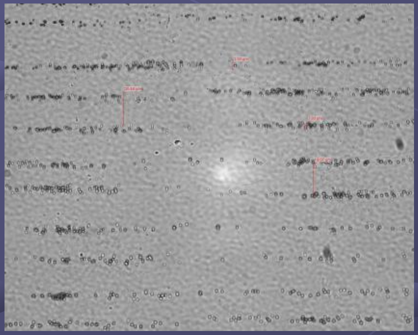
SiC Conducting Grating: Pictures

- **10X: 580um X 490um**



- **50X: d = 20um; Width = 2.5um**





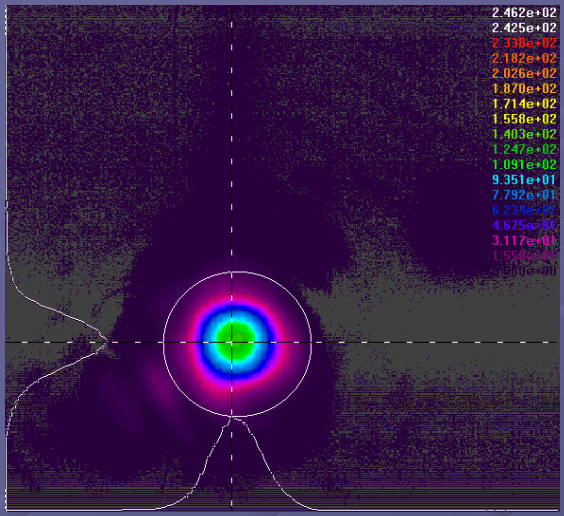
Conducting Grating Discrete Threshold:

•**Three Levels:**

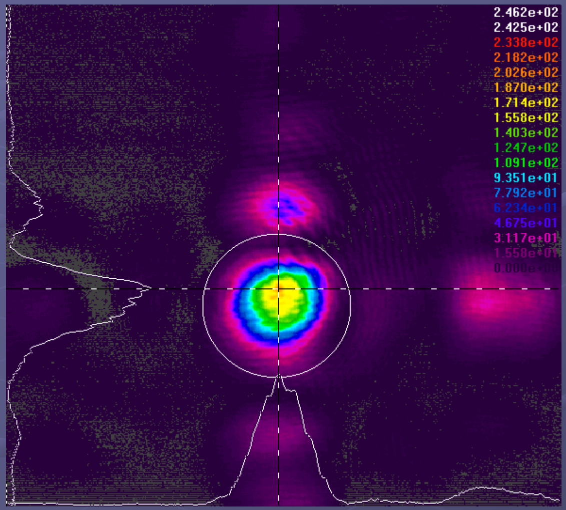
- •No Grating
- •Very poor spotted grating lines
- •Very dark grating lines

•Possibly due to many free carriers in SiC conducting

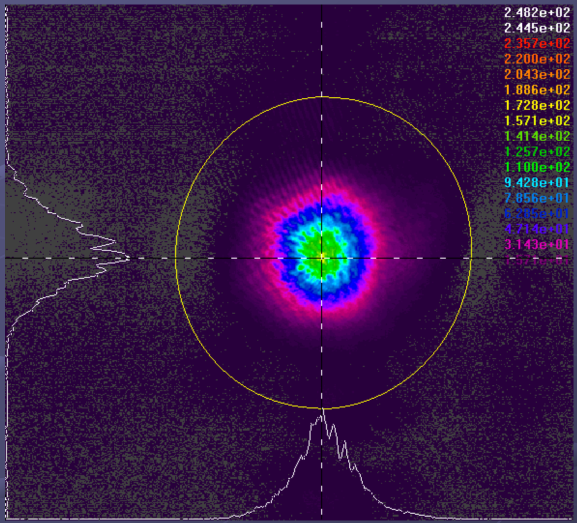
SiC Semi-Insulating Grating: Diffraction Patterns



Zero Order – Through SiC



SiC Semi-insulating First Order



SiC Conducting First Order

- Each image above was a separate Spiricon image capture and calibrated power measurement.
- Spiricon Cohu camera was calibrated with a Coherent FieldMax power meter.
- Λ = 632.8nm
- 125mm lens was used to focus HeNe beam down to 130um diameter.
- Side lobes exist due to the morphology of the gratings.
- The Conducting diffraction pattern displays very dim side lobes since the conducting grating structure were lost in the “charring” of the surface. The 1st order is very intense.

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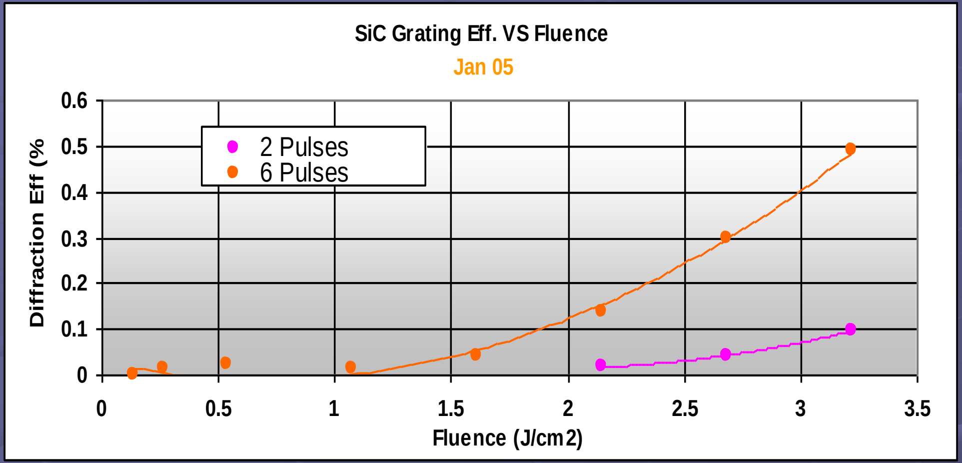
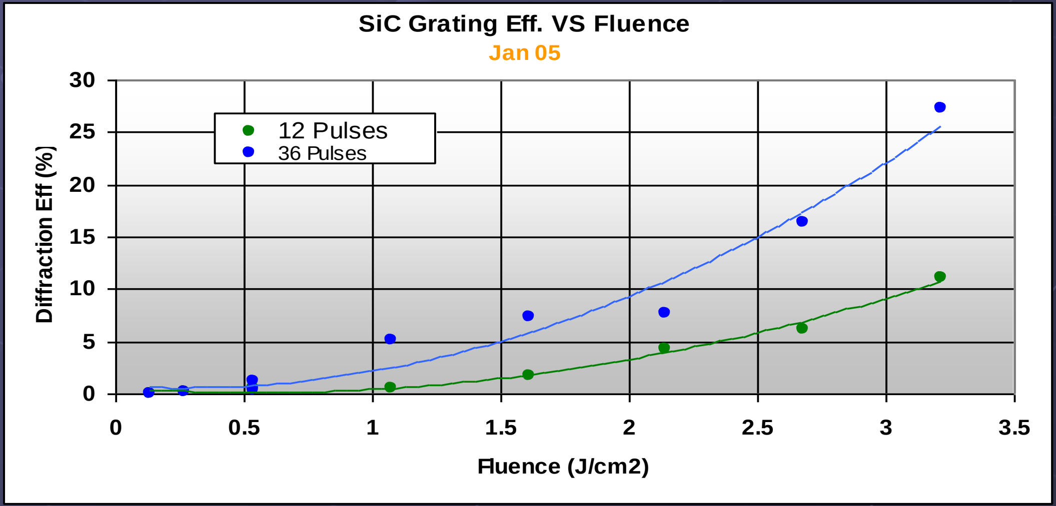
SiC Grating: DE verses Energy & Shots



2 and 6 Shots

Semi-insulating SiC Samples



12 and 36 Shots

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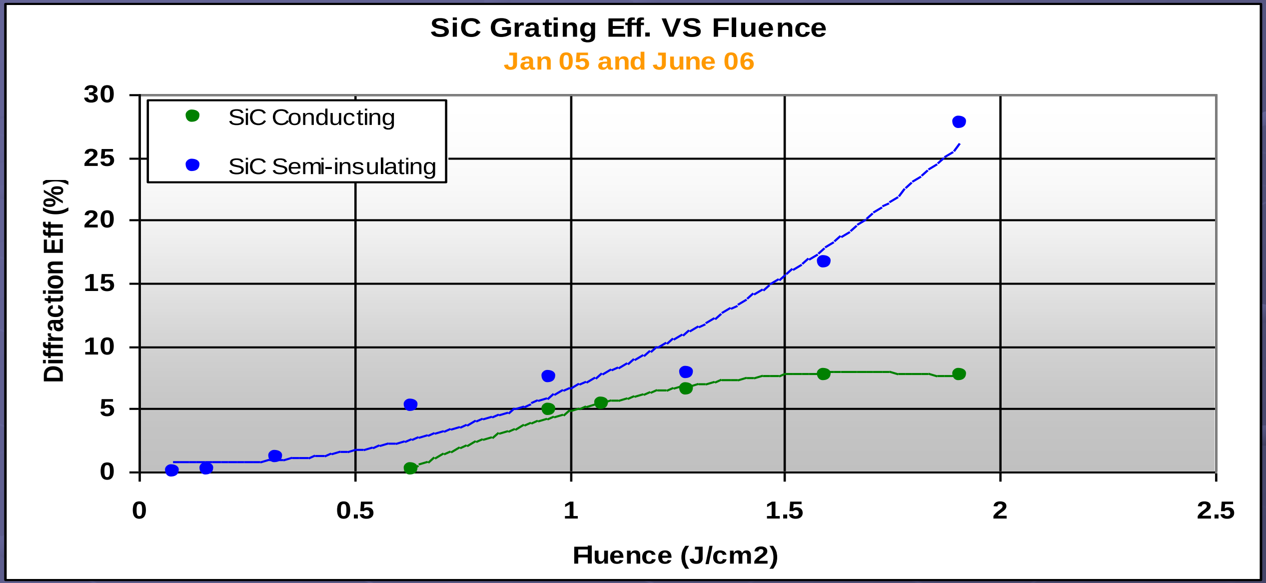
SiC Grating: DE verses Energy

All Data is for 36 Pulses



- **Semi-Insulating:**
  - Grating DE appears to increase quadratically without “rolling off”
- **Conducting:**
  - Grating DE is quadratic as well, but excessive charring causes HeNe light to be absorbed and scattered therefore “roll off”.
  - No gratings exist below 0.5 J/cm^2 due to the discrete behavior of the free electrons.

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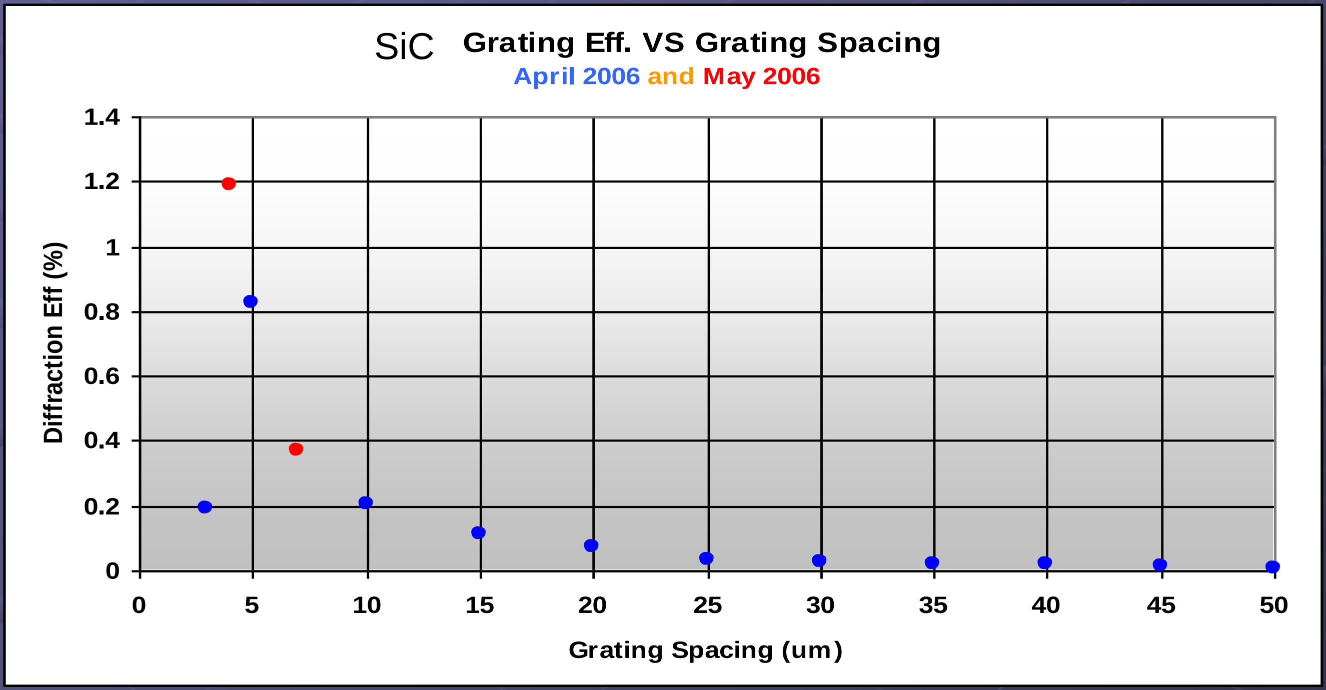
SiC Grating: DE verses Grating Spacing

All Data is for 36 Pulses:
Semi-insulating SiC



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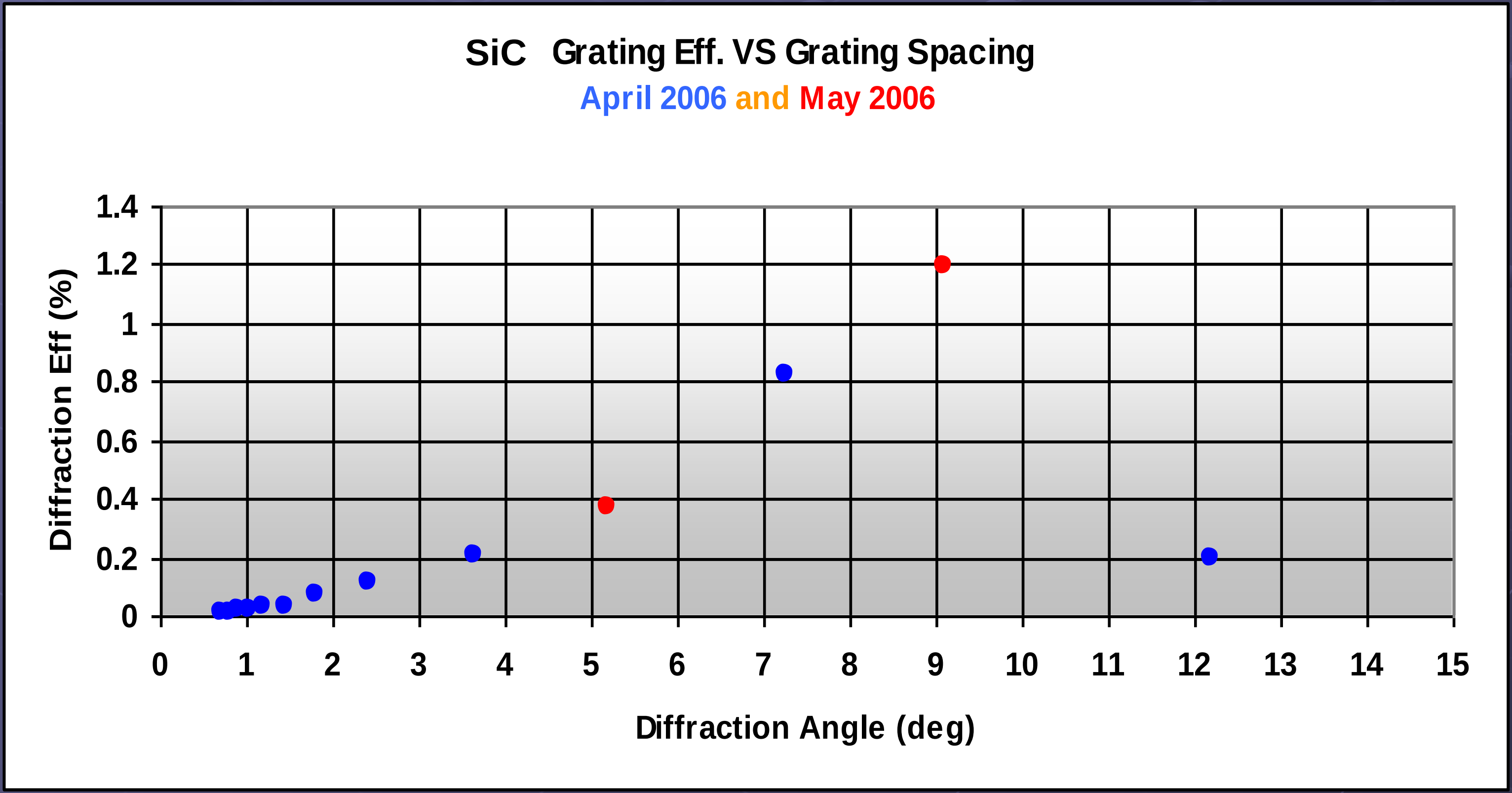
SiC Grating: DE verses Grating Spacing

All Data is for 36 Pulses:
Semi-insulating SiC



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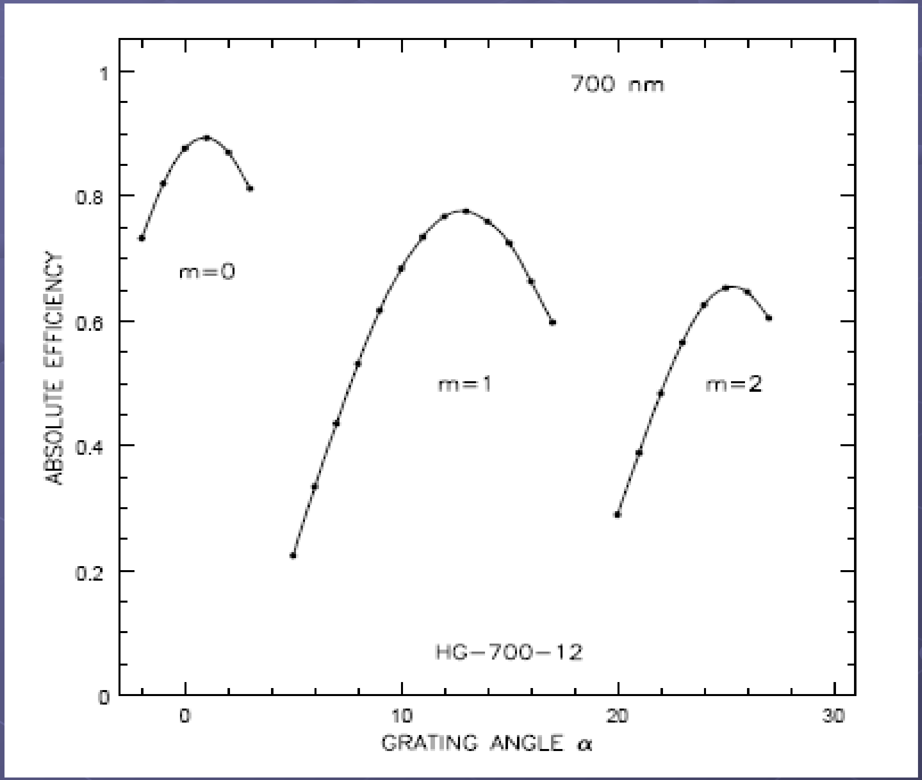
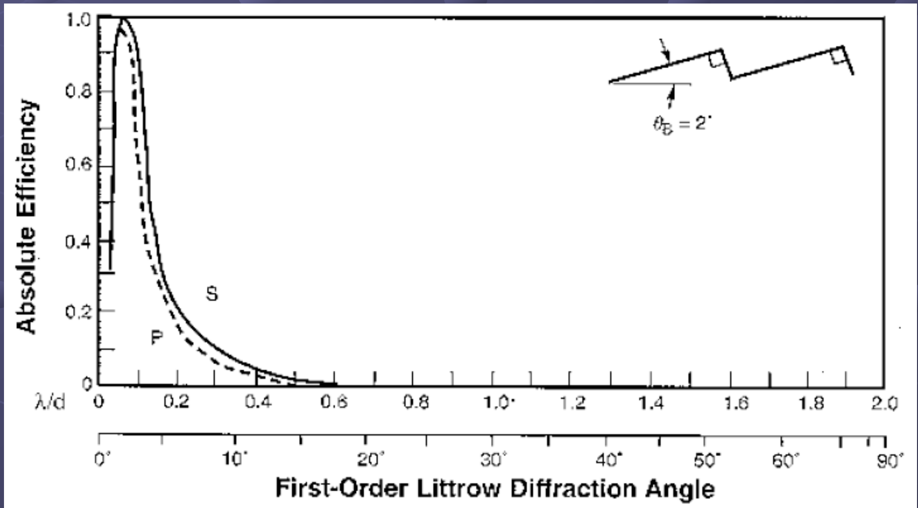
SiC Grating: DE verses Grating Spacing

Theoretical Data: Volume Gratings VS Reflection Gratings

Volume Grating



Reflection Grating



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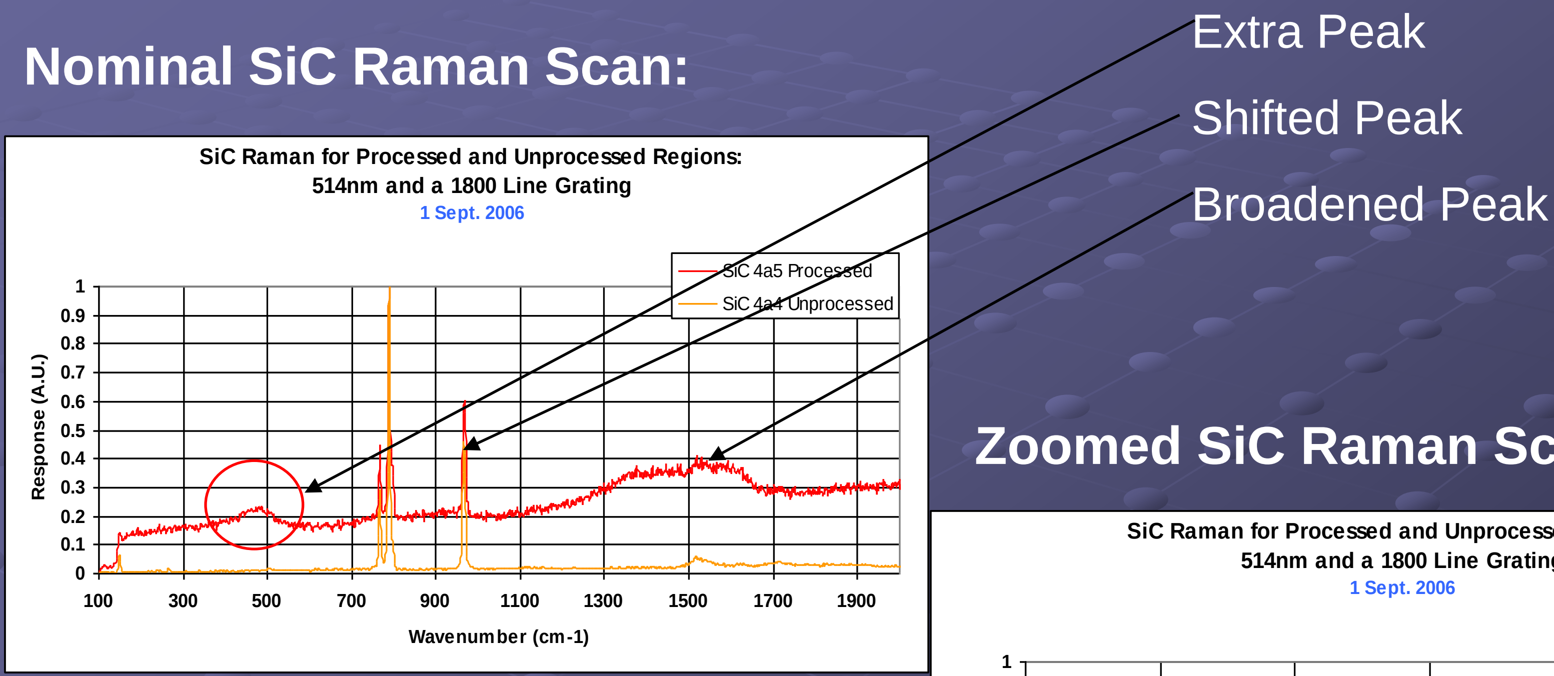
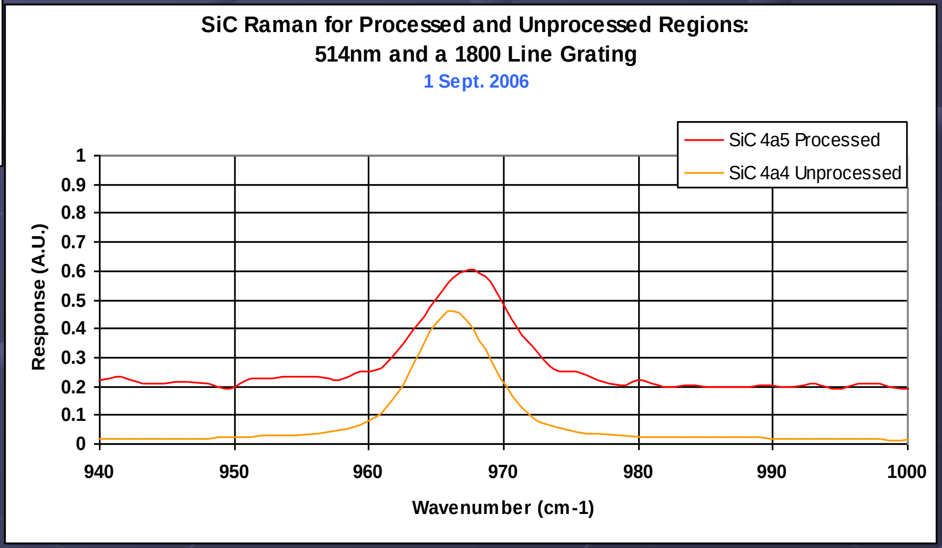
SiC Grating: Raman Results

Nominal SiC Raman Scan:



Zoomed SiC Raman Scan:



- **Extra Peak at 475 cm^{-1}**
- **Peak Shifts do Occur at 965 cm^{-1}**
- **Broadening Peak at 1512 cm^{-1}**

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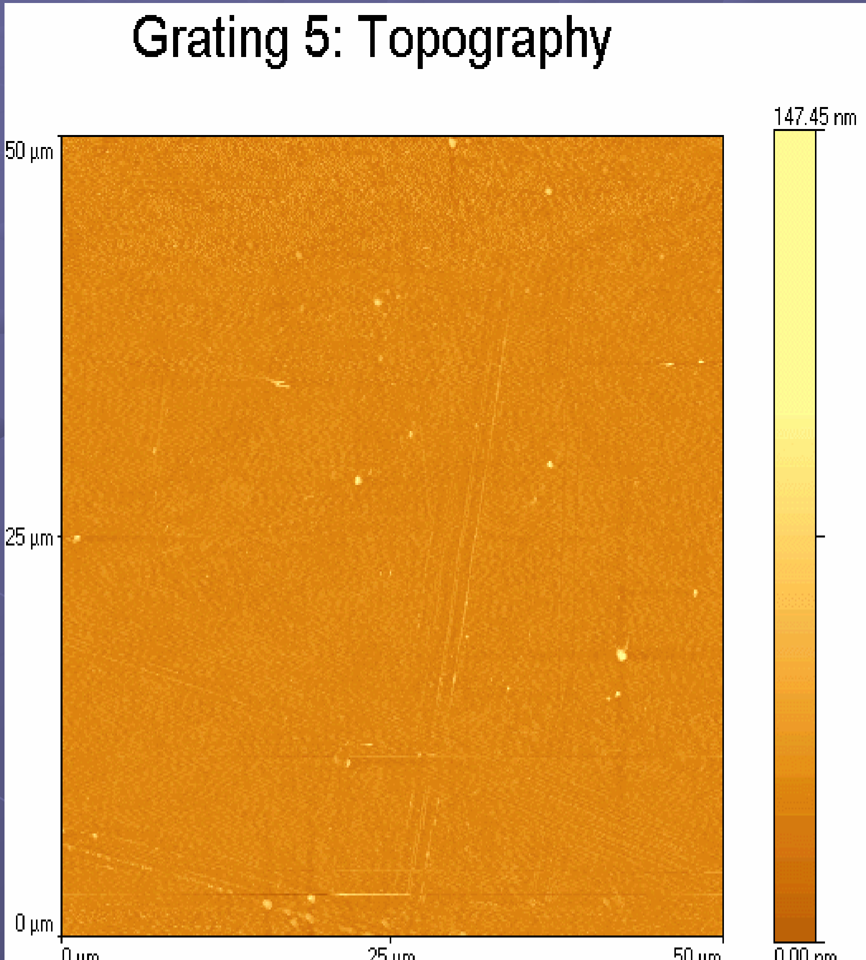
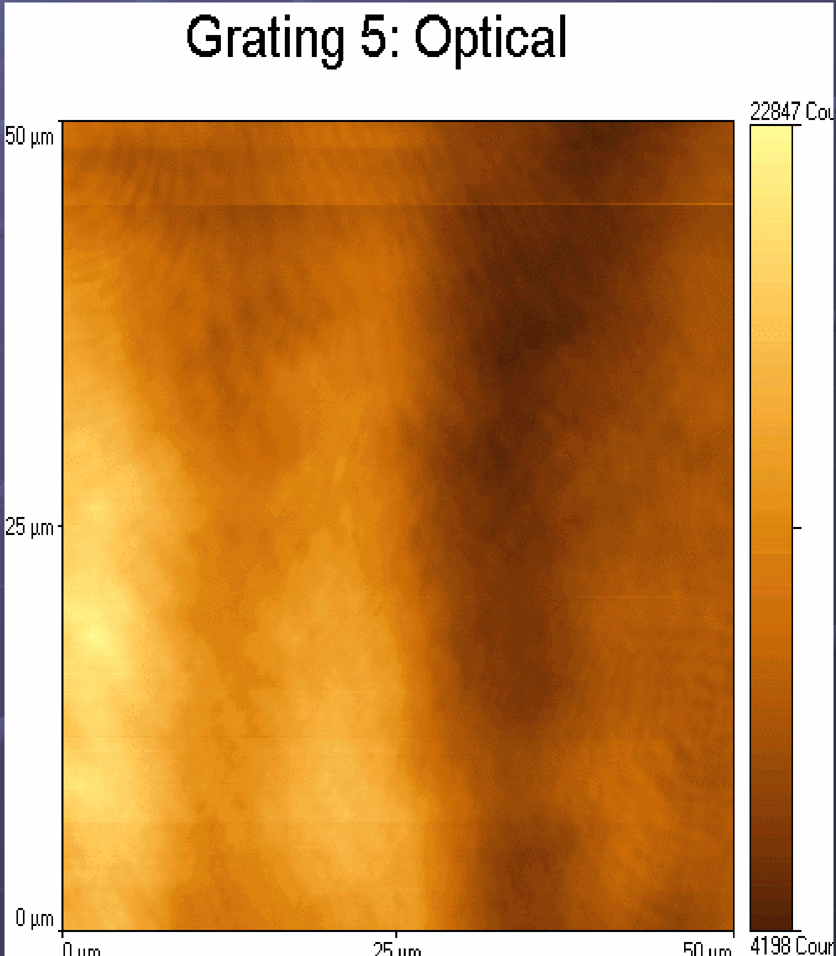
SiC Grating: NSOM Results

Grating Below Surface:



Grating: Bright or Dark Lines?



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Fourier Transform of Anamorphic Grating

$$A_1 = Gaus\left[\left(\frac{x^2}{A^2} + \frac{y^2}{B^2}\right)\right] = UFbeamExposure$$

$$A_2 = A_1 \otimes \left[\delta(x) + \delta\delta(x - x_0) + \delta\delta(x - 2x_0)\right]$$

$$Gaus(x, y) = Gaus\left(\frac{x^2}{A^2} + \frac{y^2}{B^2}\right) = \exp\left[-\pi \cdot \left(\frac{x^2}{A^2} + \frac{y^2}{B^2}\right)\right]$$

$$t_a(x, y) = A_2 \otimes \left\{\left[\frac{1}{L} \cdot comb\left(\frac{y}{L}\right) \cdot \delta(x)\right] \cdot rect\left(\frac{y}{NL}\right)\right\}$$

Transmittance Function

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Fourier Transform of Anamorphic Grating

$$t_a(x,y) = \left[\left\{ Gaus\left(\frac{x^2}{A^2} + \frac{y^2}{B^2} \right) + Gaus\left(\frac{(x \pm x_0)^2}{A^2} + \frac{y^2}{B^2} \right) + Gaus\left(\frac{(x \pm 2x_0)^2}{A^2} + \frac{y^2}{B^2} \right) \right\} \right]$$

← **Femtosecond Beam**

$$= \otimes \left\{ \left[\frac{1}{L} \cdot comb\left(\frac{y}{L} \right) \cdot \delta(x) \right] \cdot rect\left(\frac{y}{NL} \right) \right\} \bullet Gaus\left(\frac{x^2}{A^2} + \frac{y^2}{B^2} \right)$$

↑ **Grating Function**

↑ **HeNe Beam**

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Conclusion: What's Next?

- Measure Raman on FS for a Base Line
- Re-measure SiC Raman using round spot diameter (~30um)
- Confirm Index Change in SiC
- Determine Δn Magnitude (FT regression method) and/or Develop Grating Model in Mathcad/Matlab
- Investigate Causes for Change in Index
  - **X-ray Crystallography**
  - **Focused Ion Beam (FIB)**
  - **Atomic Force Microscopy (AFM)**
  - **Raman Spectroscopy**
  - **Two-Photon Fluorescence**
  - **Transmission Electron Microscopy (TEM)**
  - **Near Field Scanning Optical Microscopy (NSOM)**
  - **Energy dispersive X-ray spectroscopy** (EDX)
  - **Scanning Electron Microscope (SEM)**