Fracture Mechanics of Sapphire for High Temperature Pressure Transducers

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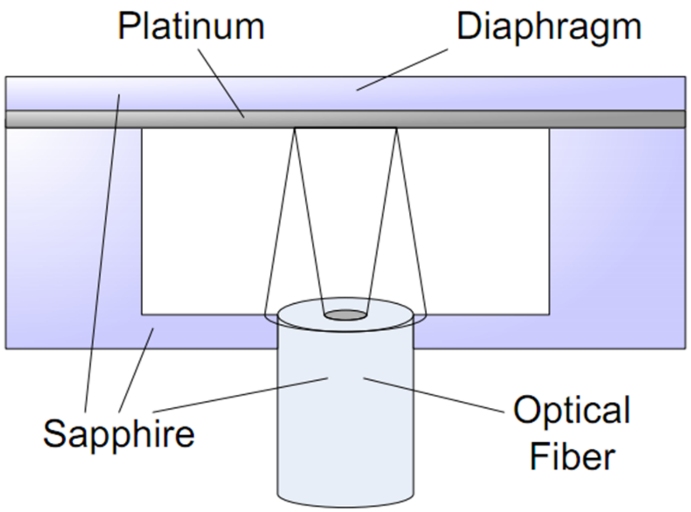
Overview

- Motivation
- Background
  - Structure Property Relations
- Current Work
  - SEM Characterization
  - Fracture Analysis
- Summary and future work

Motivation

- Commercial sensors capable of up to approximately 600℃
  - Uses SOI technology
- Alternative material sapphire: potentially capable of up to 1600℃
- Laser machining to cut specimens
  - Hard
  - Chemically Inert

Kulite Pressure Transducer



Conceptual Design

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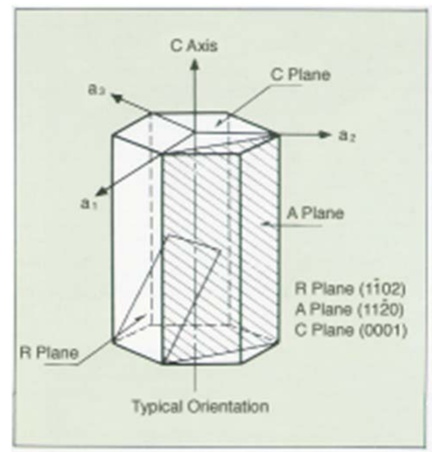
Structure-Property Relations

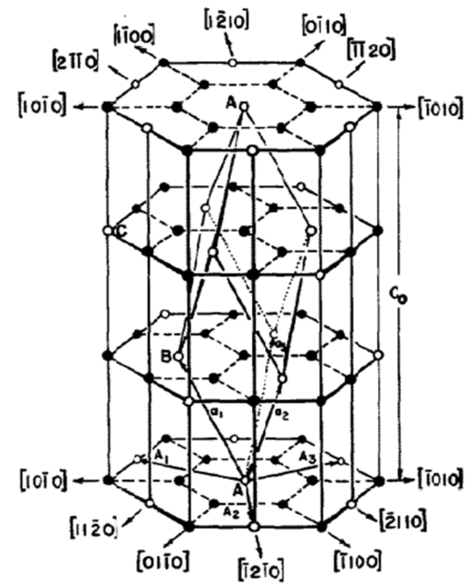
- Sapphire crystallographic structure
  - Complicated by hexagonal cage & internal rhombohedral structure
- Anisotropic elastic behavior
  - Rhombohedral—not hexagonal

$$\sigma_{ij} = c_{ijkl}\varepsilon_{kl}$$

- Melting temperature 2030 ℃



Kyocera wafer cuts



Kronberg, acta metallurgica, vol.5, 1957

Table 4. Determined elastic constants of corundum and their standard deviations in GPa. Previous data are also shown

C_{11}	C_{33}	C_{44}	C_{12}	C_{13}	C_{14}	Ref.
496.9 ± 1.4	500.5 ± 1.6	146.8 ± 0.2	162.3 ± 1.6	115.5 ± 1.6	−21.9 ± 0.2	present work
496	502	141	135	117	−23	[8]
496.8 ± 1.8	498.1 ± 1.4	147.4 ± 0.2	163.6 ± 1.8	110.9 ± 2.2	−23.5 ± 0.3	[9]
490.2	490.2	145.4	165.4	113.0	−23.2	[10]
497.4	499.4	147.4	164.0	112.3	−23.6	[11]
497.60 ± 0.18	501.85 ± 0.21	147.24 ± 0.13	162.6 ± 0.4	117.18 ± 0.19	−22.90 ± 0.11	[12]

Ohno, *Phys. Chem. Solids Vol. 47, No. 12. pp.* I ION 108. *1986*

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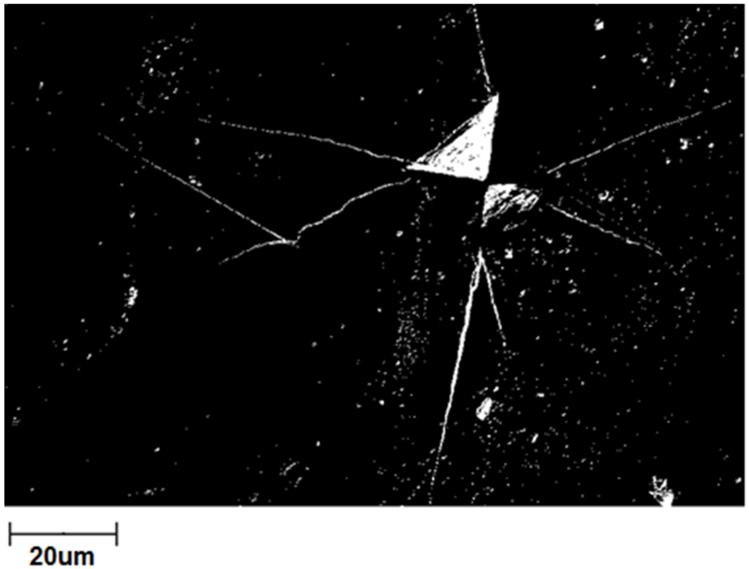
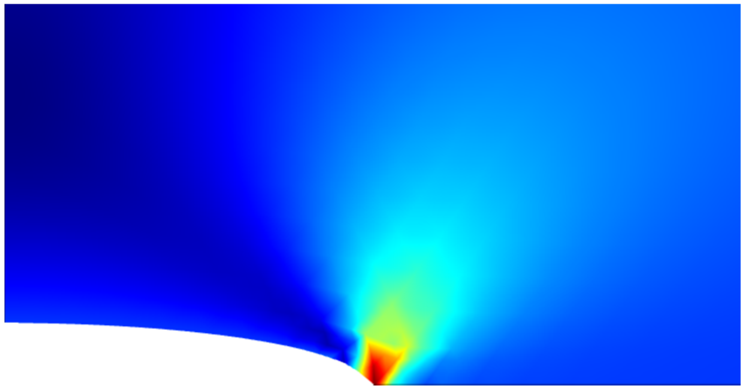
SEM Characterization

- Fracture characterization
  - Virgin vs. laser machining
- Crack opening quantified
  - Intrinsic crack tip toughness measured





Crack opening displacement

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Anisotropic Fracture Stroh's Formalism

- Equilibrium
  - $\nabla \cdot \sigma = 0$
- Constitutive Relation
  - $\sigma_{ij} = C_{ijks} u_{k,s}$
- Boundary Condition
  - $t_i = \sigma_{ji} n_j$
- Generalized Stress Potential
  - $u_i = 2 \sum_{j=1}^{3} Re\{Aijf(z_j) q_j\}$
- Generalized displacement potential
  - $\varphi_i = 2 \sum_{j=1}^{3} Re\{B_{ij} f(z_j) q_j\}$

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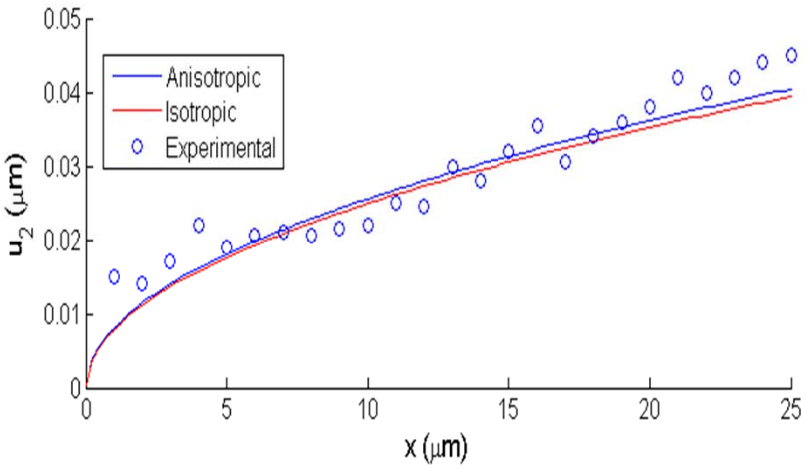
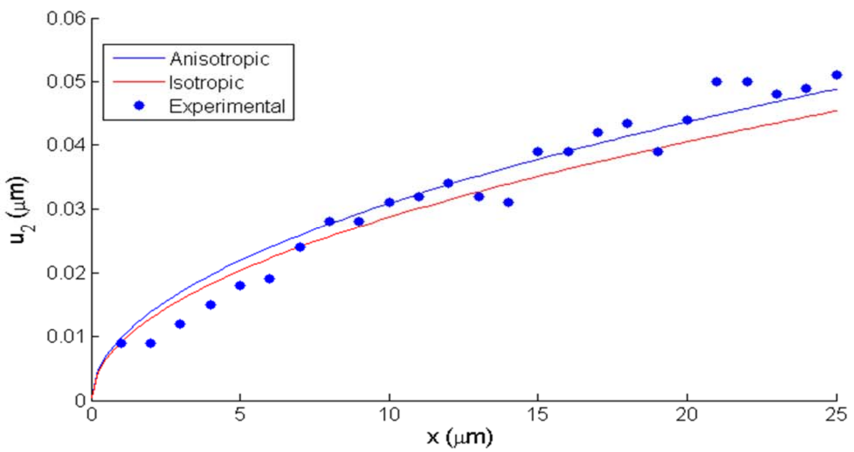
Fracture Toughness

- $K_{1c} \cong 2.3$ MPa*$m^{1/2}$
- Gc ≅ 11.65 N/m



Indentation at ~0°

- $K_{1c} \cong 2.65$ MPa*$m^{1/2}$
- Gc ≅ 16.22 N/m



Indentation at ~45°

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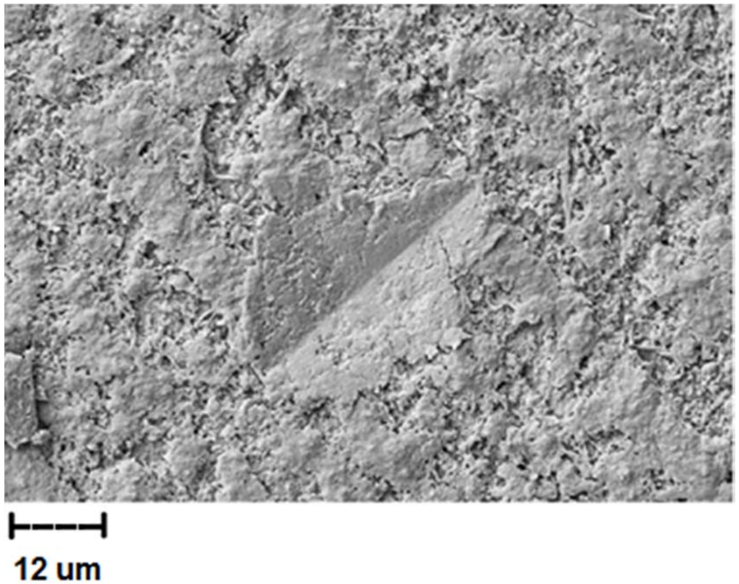
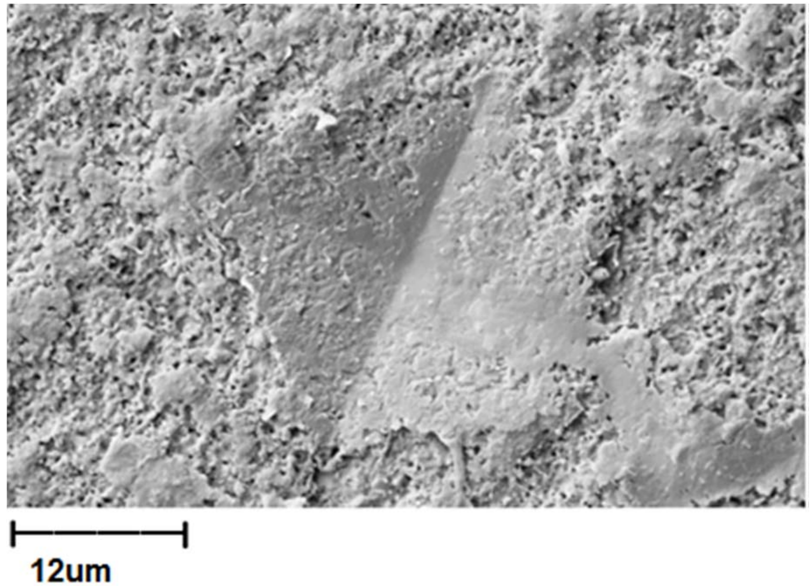
Toughness Induced Laser Machining

- Preliminary Vicker's indentation characterization
- No visible cracks
- Laser machining parameters
  - 10 kHz rep rate, 10 mm/s scanning speed, 3.8 J/cm^2 fluence, 3um stepover





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Summary

- Correlated crystal structure with anisotropic elastic properties
- Quantified crack tip toughness in virgin sapphire specimens
  - Good correlation with data in literature
- Laser machining effects on fracture
  - Unusual toughness enhancement
- Hypothesis: Laser induced dislocations
  - TEM characterization and dislocation/fracture modeling currently underway

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Backup Slides

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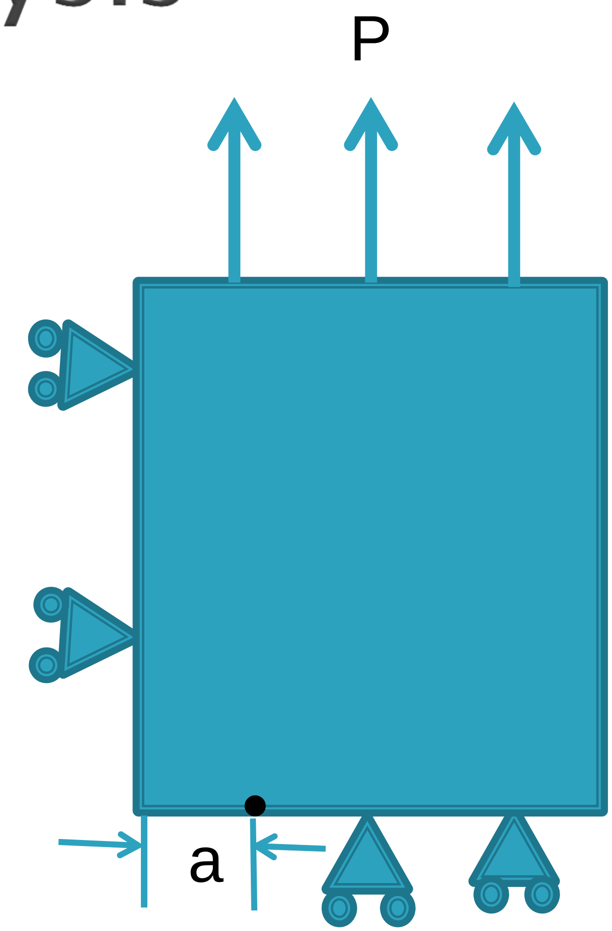
FEM Analysis



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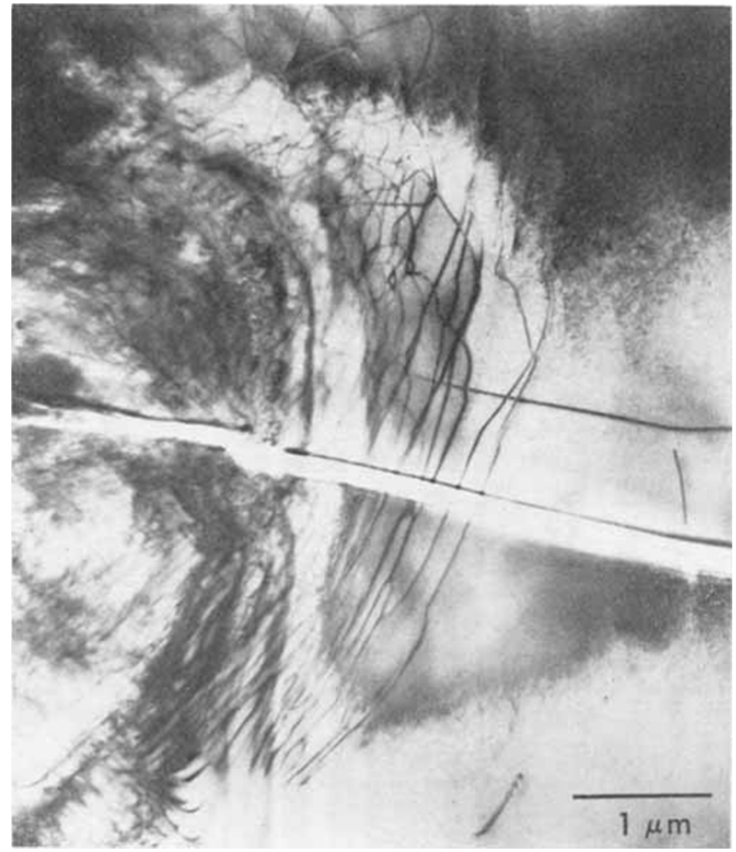
Dislocation Mechanics

- Basal dislocations associated with a 100-g indentation on a (0001) basal plane section
- Specimen polished with abrasive paper.
- How does laser machining affect the properties of sapphire? Are dislocations induced during the process?



Hockey ,Journal of The American Ceramic Society Vol. 54, 1971

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