SAND2014-4696C

# SIDEWALL ROUGHNESS EFFECTS ON SOI MEMS FRACTURE STRENGTH

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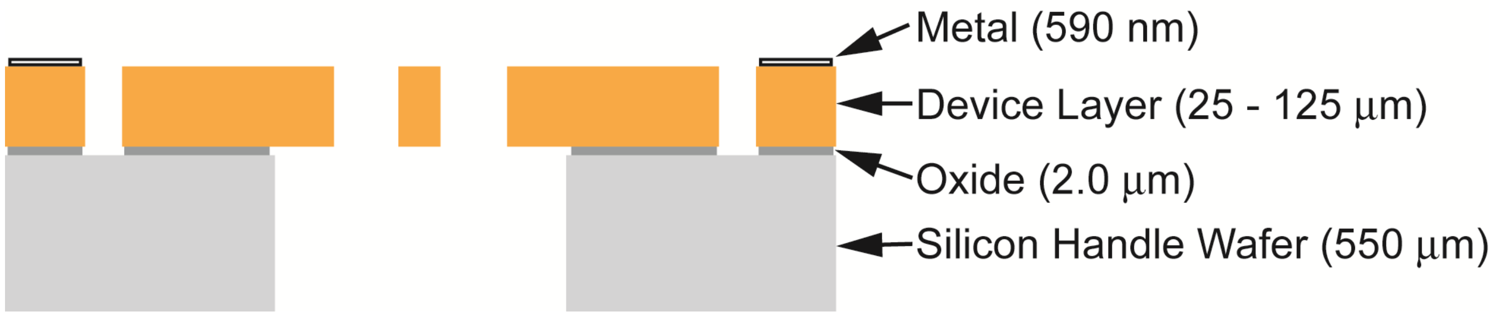
# Outline

- SOI processing and sidewall features
- Strength testing and results
- Analysis of critical flaws and strength distributions

# Details of the SOI Process

-used to fabricate the structures for this investigation

***Schematic Cross-Section of fabricated SOI structures***




- Handle wafer p-doped Silicon (Ultrasil Corp.)
- Device layer ⟨100⟩ orientation
- Test sample ligaments aligned with a ⟨110⟩ direction

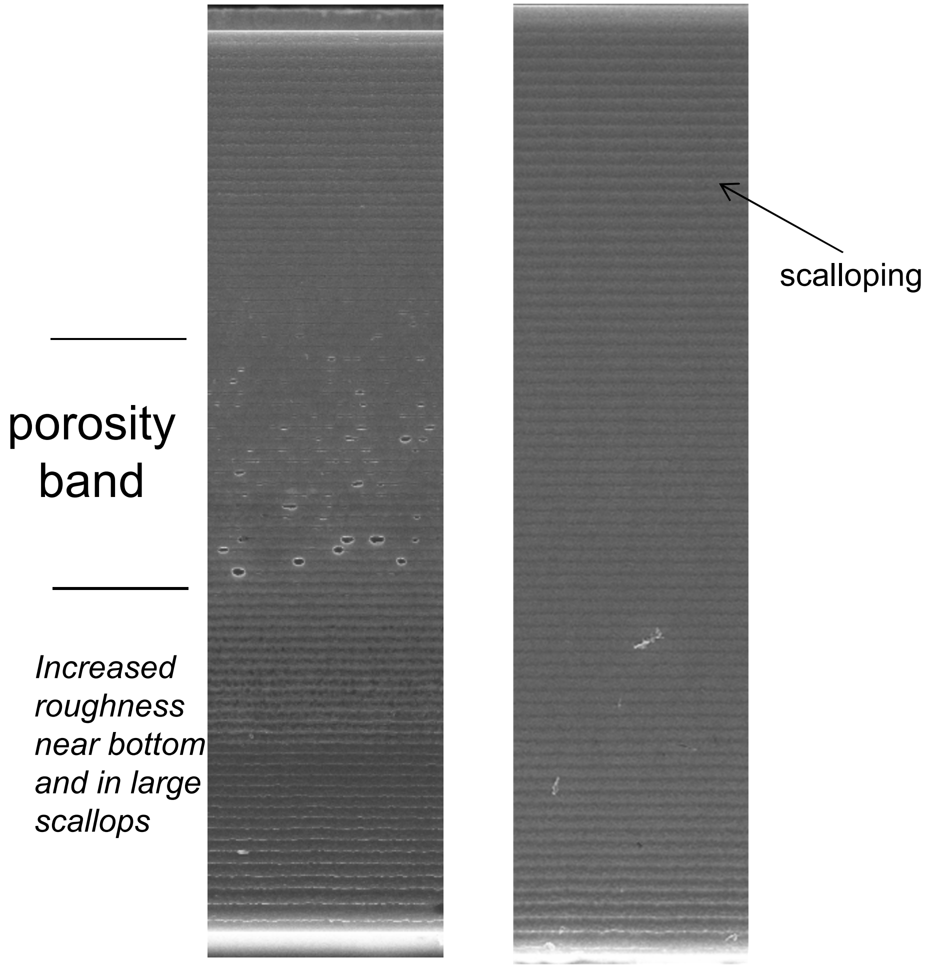
DRIE process – alternating etching and passivation process steps which creates fairly vertical sidewalls.

*More Processing Details:*

Buchheit, T.E. and Phinney, L.M. "Sidewall Roughness Effects on SOI MEMS Fracture Strength", to be submitted JMEMS 7/2014

# Sidewall Features in 25 µm Device Layers

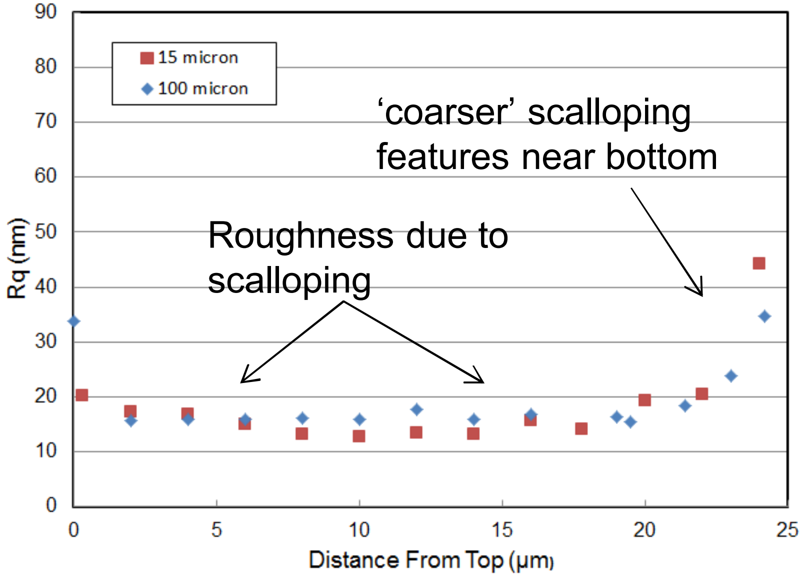
SEM image




Trench Width 15µm

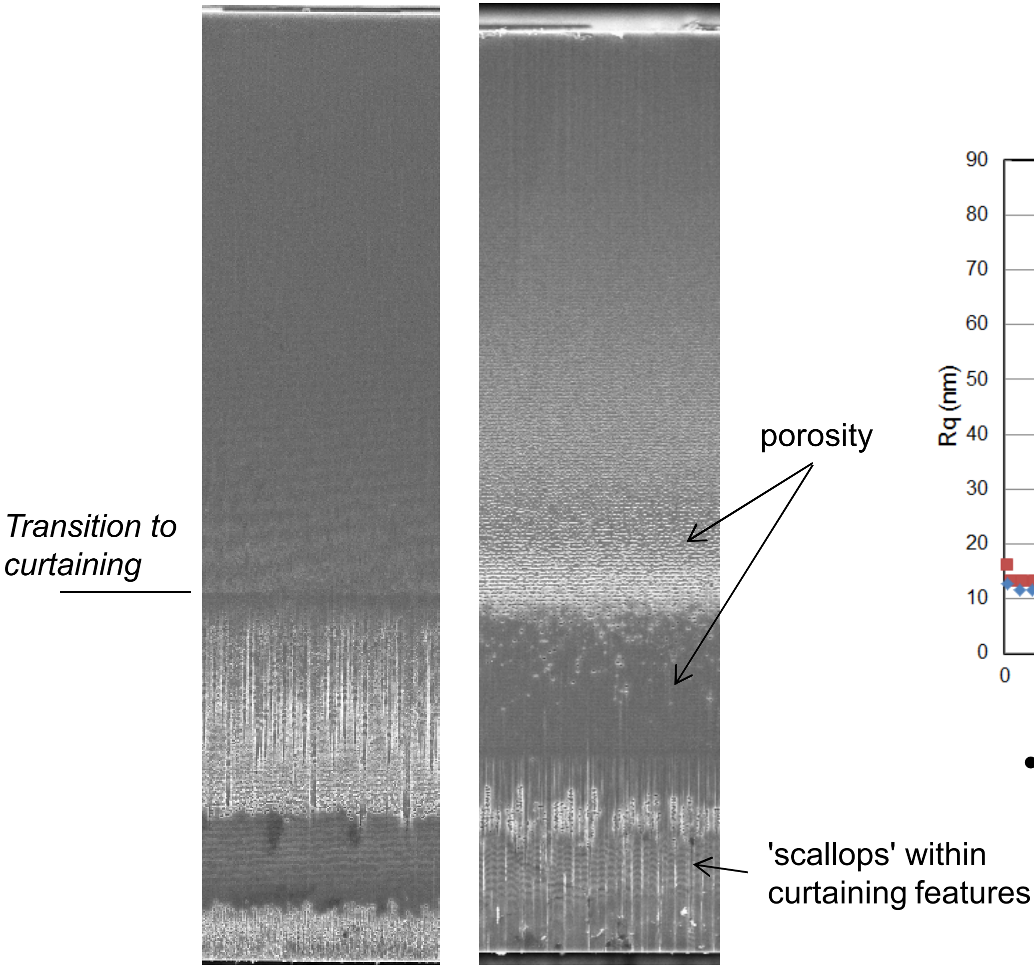
Trench Width 100µm

Result from AFM scan



# Sidewall Features in 125 µm Device Layers

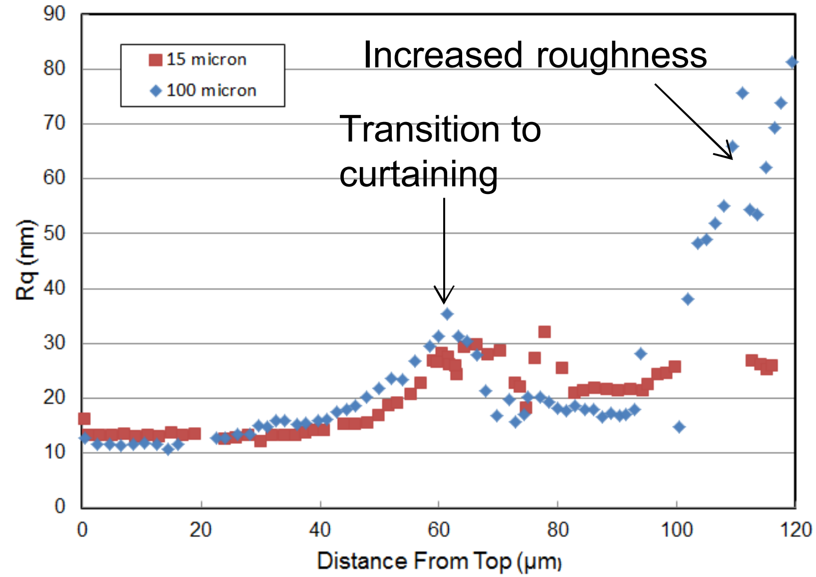
SEM image




Trench Width 15µm

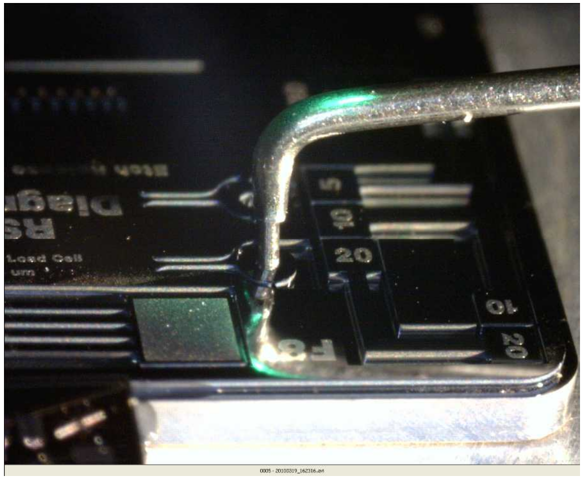
Trench Width 100µm

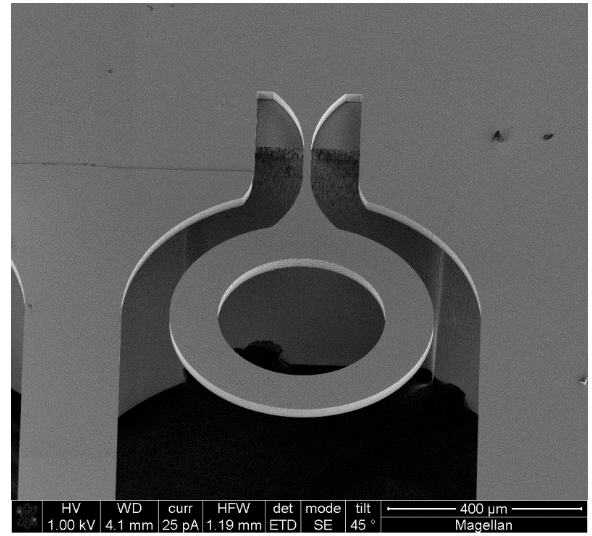
Result from AFM scan

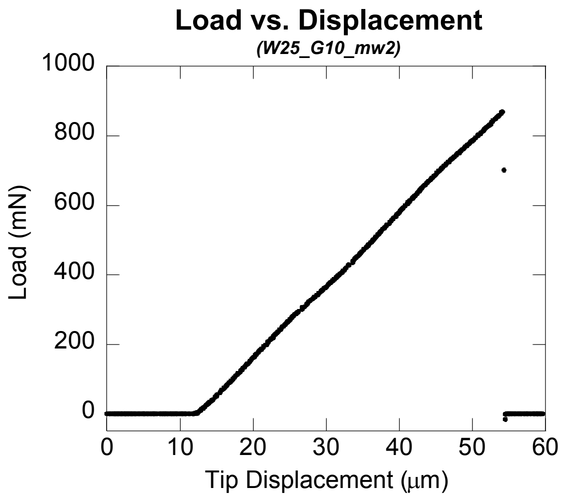


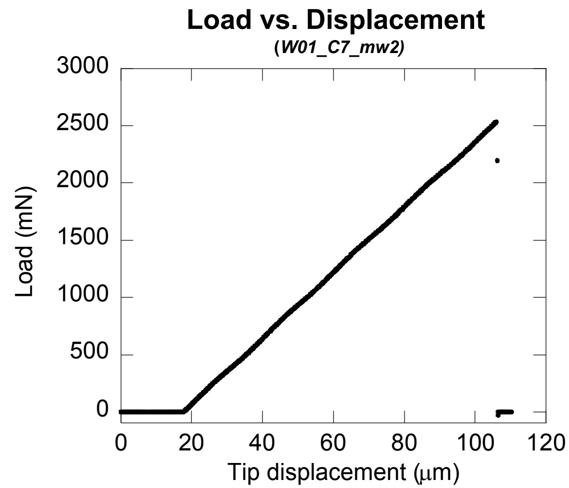

- Not a significant difference due to adjacent trench width except near bottom of 125 um device layer

# Typical Load-Displacement (Strength) Measurements






- No alignment feature and much higher loads to failure than previous similar test structures/studies

*Sandia SMM ~20 mN (Boyce et al. 2007), MUMPS SOI ~ 250 mN (Miller et al. 2007)*

# Pull-Tab Test Geometry and Experiments

### 25 µm device layer

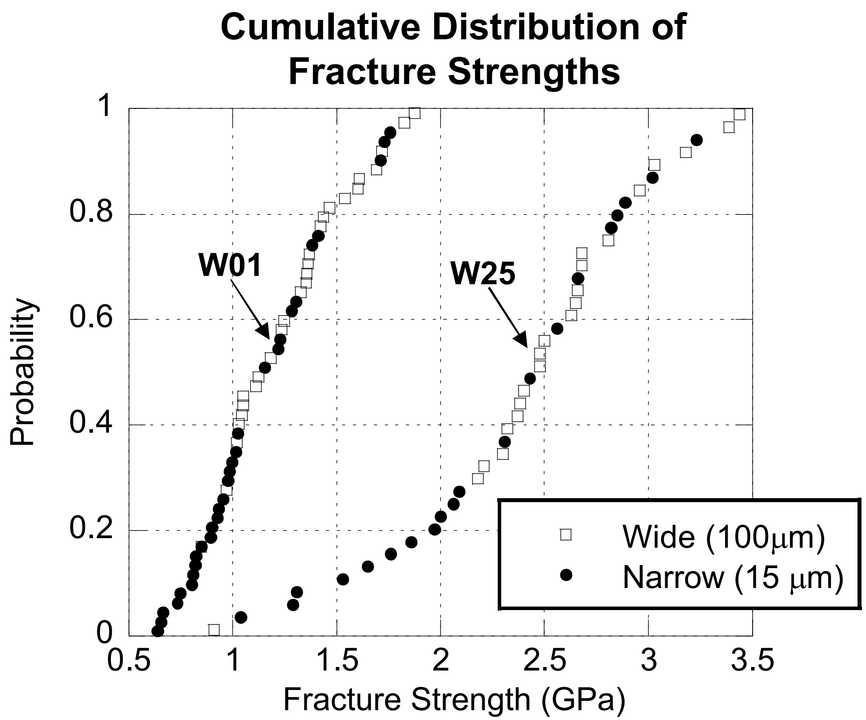
| Specimen Designation | Length (µm) | Trench Width (µm) | Aspect Ratio | No. of Tests |
|---|---|---|---|---|
| short-narrow (**W25**-sn) | 100 | 15 | 1.667 | 9 |
| medium-narrow (**W25**-mn) | 500 | ↓ | ↓ | 9 |
| long-narrow (**W25**-ln) | 3000 | ↓ | ↓ | 3 |
| short-wide (**W25**-sw) | 100 | 100 | 4 | 9 |
| medium-wide (**W25**-mw) | 500 | ↓ | ↓ | 6 |
| long-wide (**W25**-lw) | 3000 | ↓ | ↓ | 6 |

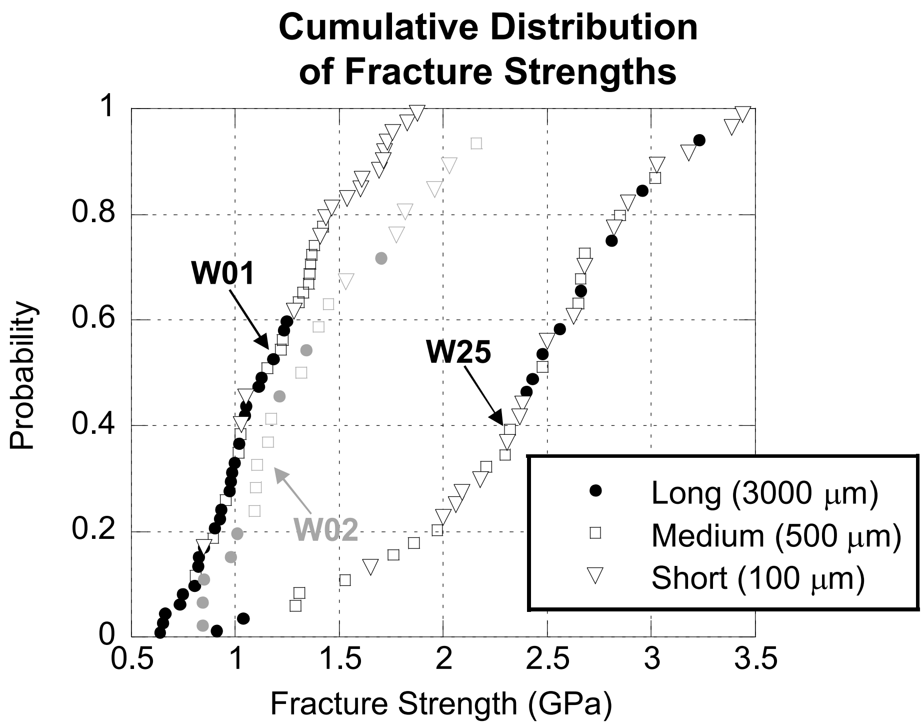
### 125 µm device layer

| Specimen Designation | Length (µm) | Trench Width (µm) | Aspect Ratio | No. of Tests *W01/W02* |
|---|---|---|---|---|
| short-narrow (**W01**-sn) | 100 | 15 | 8.333 | 5 |
| medium-narrow (**W01**-mn) | 500 | ↓ | ↓ | 11 |
| long-narrow (**W01**-ln) | 3000 | ↓ | ↓ | 14 |
| short-wide (**W01/W02**)- sw | 100 | 100 | 1.25 | 11/8 |
| medium-wide (**W01/W02**)-mw | 500 | ↓ | ↓ | 6/8 |
| long-wide (**W01/W02**)-lw | 3000 | ↓ | ↓ | 9/8 |

- Two device layer thicknesses across three wafers (W25, W01, W02)
- 3 lengths spanning 2 orders of magnitude
- Two adjacent trench widths (may play a role in sidewall roughness)

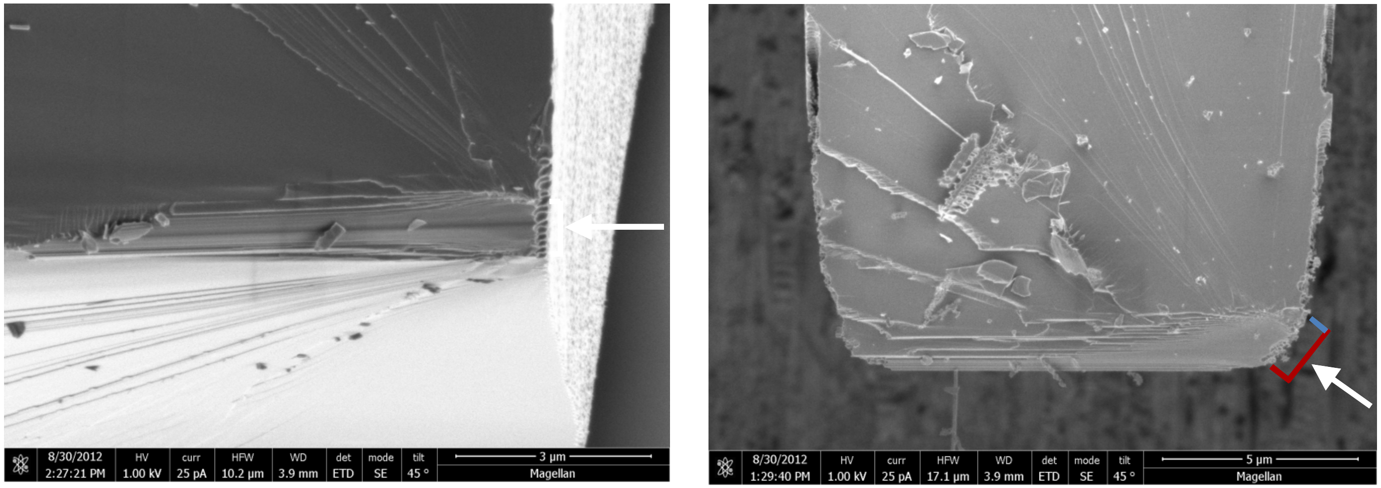
# Cumulative Distribution of Strength Results across Three Wafers (**W01,W02**- 125 μm and **W25** – 25 μm)



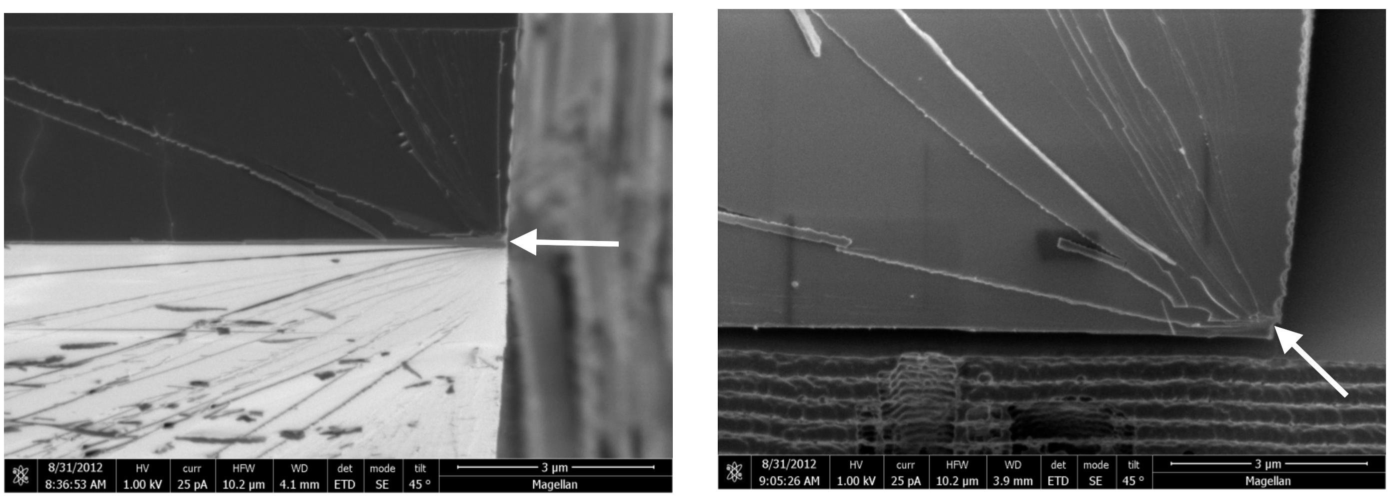




- Narrow trench width seemed to lower strength distribution
- **W01**, **W02** distributions are similar (suggests limited wafer to wafer variation)
- Length dependence in **W01** (125 μm) wafer results

# Typical Fracture Initiation Sites in W25 Ligaments




Series of scallop features near and at bottom corner




Single features at mid-section (porosity) or bottom corner

# Typical Fracture Initiation Sites in W01 and W02 Ligaments

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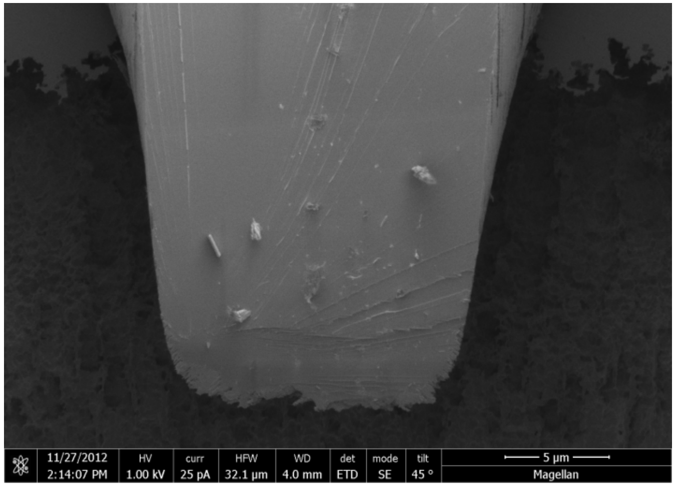
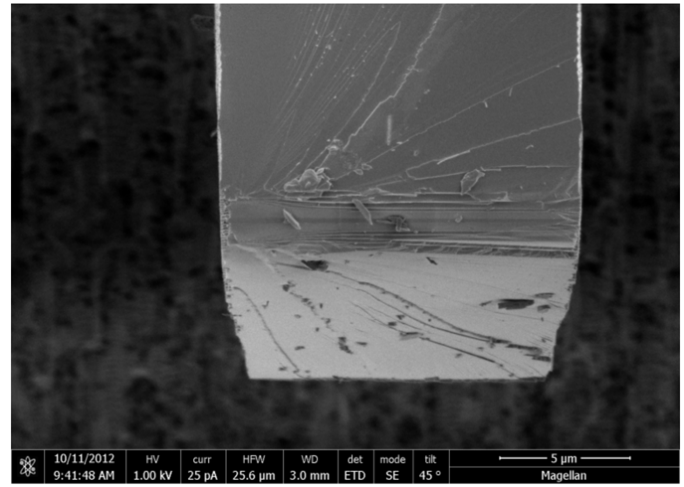
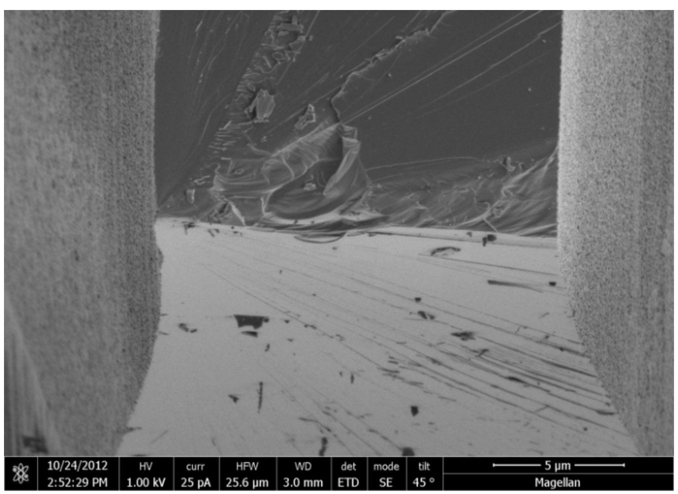


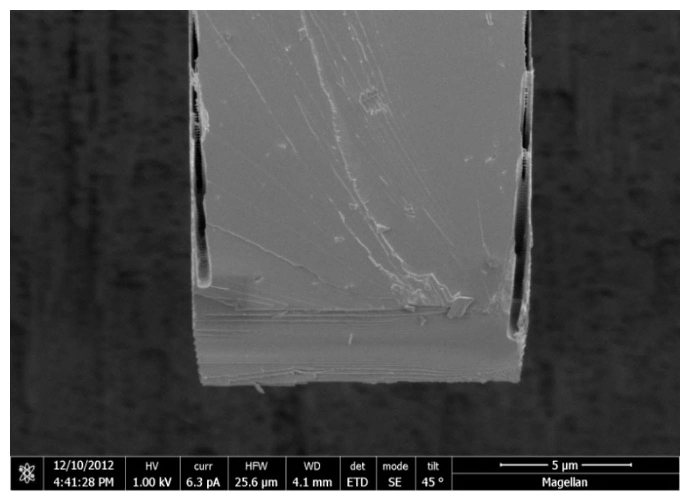

Roughened bottom




Sidewall scalloping features near bottom

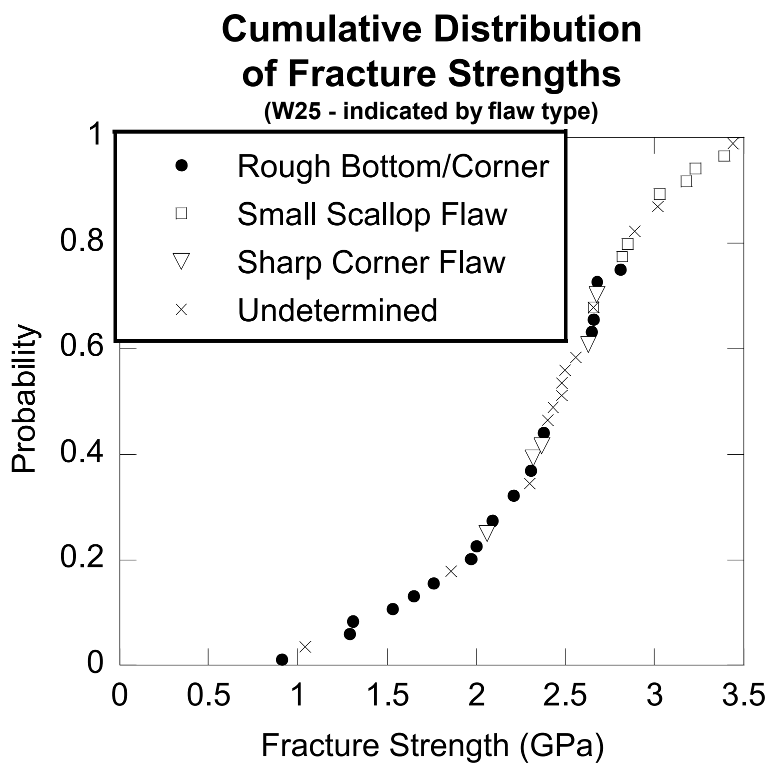


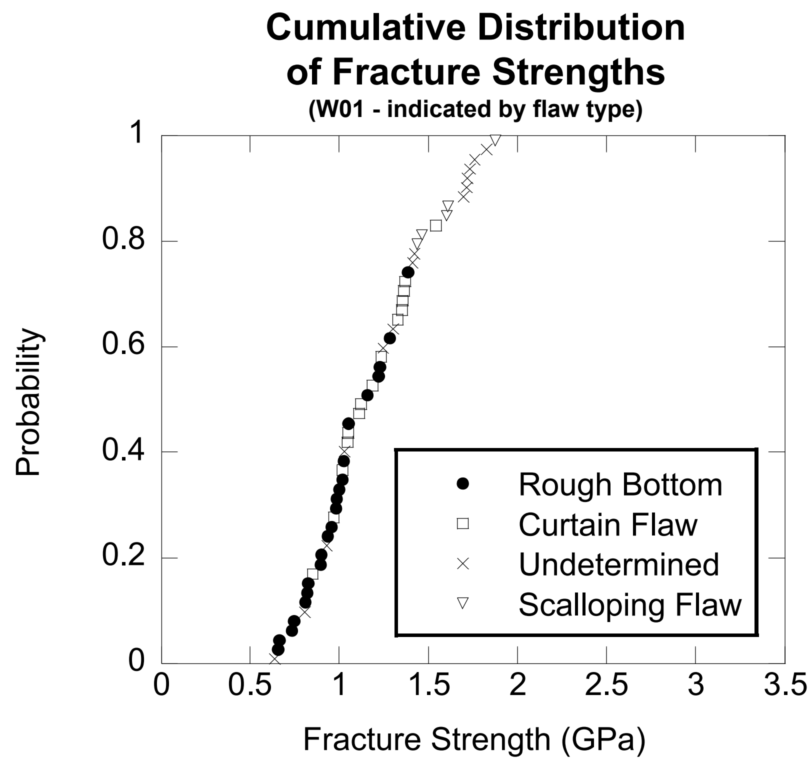

Near surface pore feature




W02 curtaining/digging feature

# Fracture Strength Distributions Designated by Flaw Type



# Estimation of Weibull parameters

| **W01 Estimation of Weibull Parameters** | | | | |
|---|---|---|---|---|
| **Specimen Designation** | **Gage Length (μm)** | **No. of Tests** | **m** *unbiased* | $\sigma_{char}$ **(GPa)** *unbiased* |
| **W01**-lw+ln | 3000 | 24 | 5.705 | 1.003 |
| **W01**-mw+mn | 500 | 15 | 7.299 | 1.260 |
| **W01**-sw+sn | 100 | 16 | 7.564 | 1.639 |

| **W25 Estimation of Weibull Parameters** | | | | |
|---|---|---|---|---|
| **Specimen Designation** | **Gage Length (μm)** | **No. of Tests** | **m** *unbiased* | $\sigma_{char}$ **(GPa)** *unbiased* |
| **W25**-lw+ln | 3000 | 10 | 3.545 | 2.565 |
| **W25**-mw+mn | 500 | 15 | 3.699 | 2.469 |
| **W25**-sw+sn | 100 | 17 | 5.246 | 2.753 |
| **W25**-(lw+mw+sw) | - | 21 | 5.431 | 2.823 |
| **W25**-(ln+mn+sn) | - | 21 | 3.879 | 2.385 |
| **W25**-all | - | 42 | 4.461 | 2.627 |

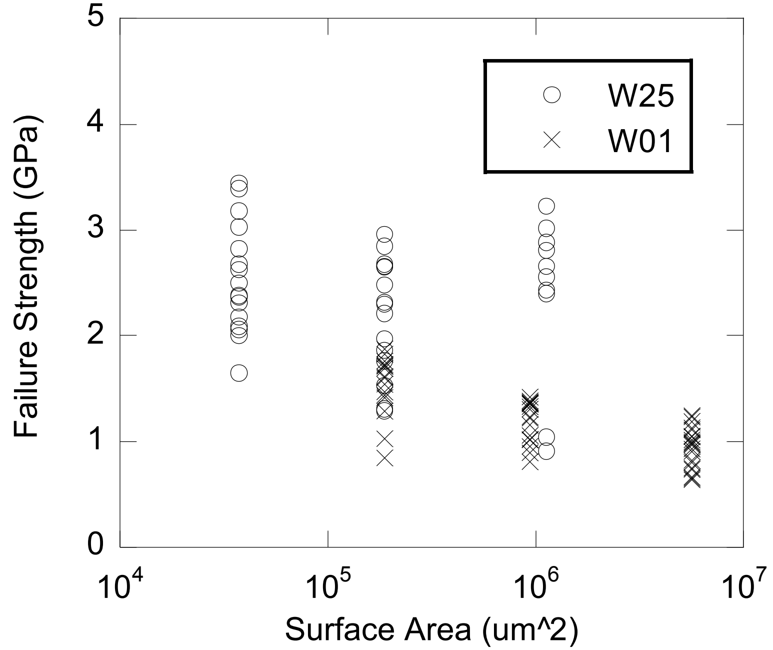
Broad distribution of strengths

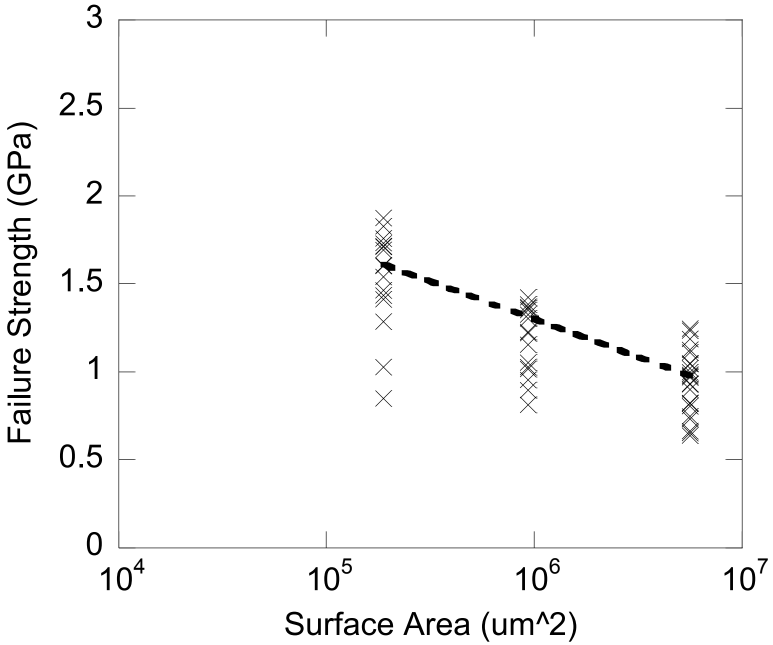
Adjacent trench width does not seem to influence the distributions.

Characteristic strength does not scale with surface area in W25 samples.

-maximum likelihood estimation per ASTM 1239

# Does Fracture Strength Scale with Surface Area?




$$\left(\frac{\sigma_1}{\sigma_2}\right) = \left(\frac{A_2}{A_1}\right)^{1/m}$$

# Conclusions

- Processing induced sidewall features and bottom features were significant and dictated the strength distributions generated from experiments on the pull-tab test structures.

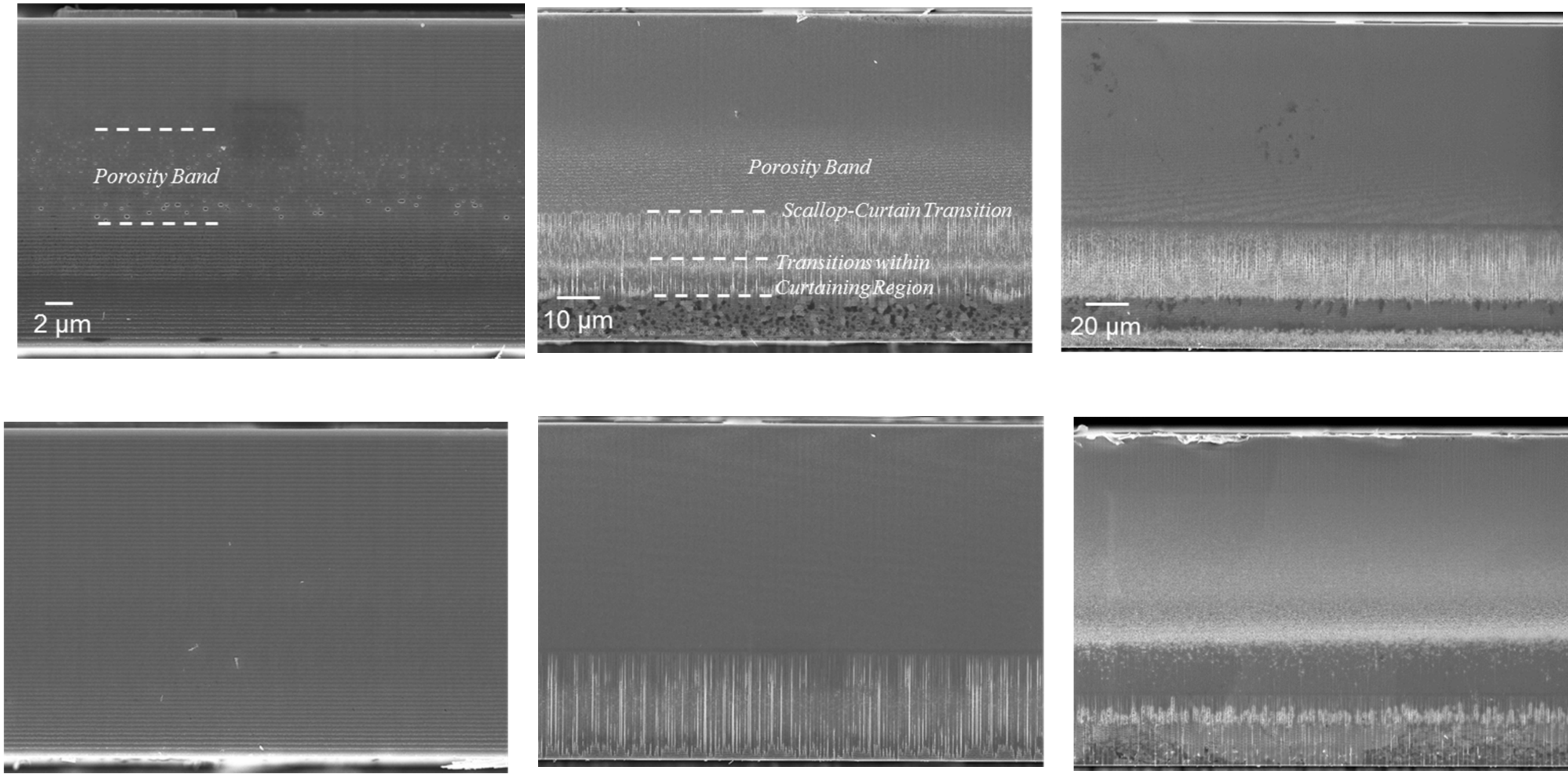
- Fracture strengths ranged from 1.0– 3.5 GPa for the 25 μm thick samples and from 0.6 – 2.2 GPa for the 125 μm thick samples.

- Current processing methods may be sufficient for many MEMS designs/applications.

- Analysis of the fracture strengths suggested a spatially distributed flaw population along length of pull tab strength test structures in 125 μm specimen, but not along length of 25 μm test structures.

# Processing Produced a Range of Sidewall Defects

25 µm device layer | 75 µm device layer | 125 µm device layer




- Suspected a trend in sidewall morphology due to height and adjacent trench width (aspect ratio = device layer height/adjacent trench width)