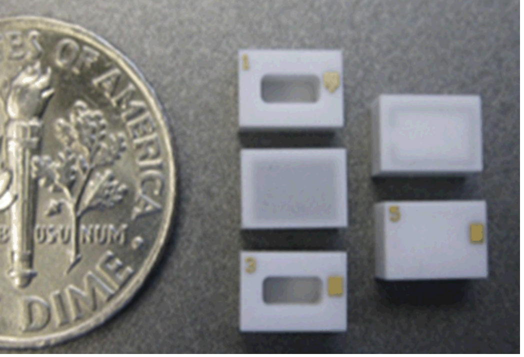

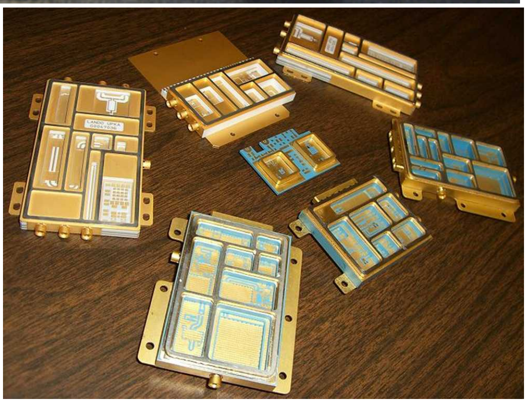

SAND2017-0482C

# Failure Analysis and Sub-critical Crack Growth (SCG) Characterization of Pt-$Al_2O_3$ High Temperature Co-fired (HTCC) Ceramics

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# Presentation Outline

Introduction

- Implantable Medical Devices
- HTCC- What is it, what it does, how it is made

Experimental Plans

- Mechanical Testing for Reliability
- Test Vehicles and Approach

Results

- Iterative Materials Processing and Testing
  - Phase I, II, and III
- Strength, Stresses and Failure Modes

Conclusions

# Implantable Medical Devices




Hydrocephalus
Sinus Diseases
Sinus Augmentation
Sleep Disordered Breathing
Cervical Degenerative Disc Disease
Thyroid Conditions

Parkinson's Disease
Essential Tremor
Dystonia**
Obsessive-Compulsive Disorder**

Atrial Fibrillation
Heart Failure
Congenital Heart Disease
Heart Rhythm Disorders
Angina*
Coronary Artery Disease
Heart Valve Disease

Otologic Disorders
Meniere's Disease

Aortic Disease

Severe Spasticity associated with Multiple Sclerosis, Cerebral Palsy, Stroke and Spinal Cord and Brain Injuries

Scoliosis
Spinal Fracture
Lumbar Spinal Stenosis
Degenerative Disc Disease
Pelvic Trauma

Chronic Pain
Nausea and Vomiting associated with Gastroparesis**
Diabetes
Overactive Bladder and Urinary Retention
Fecal Incontinence

Peripheral Vascular Disease*

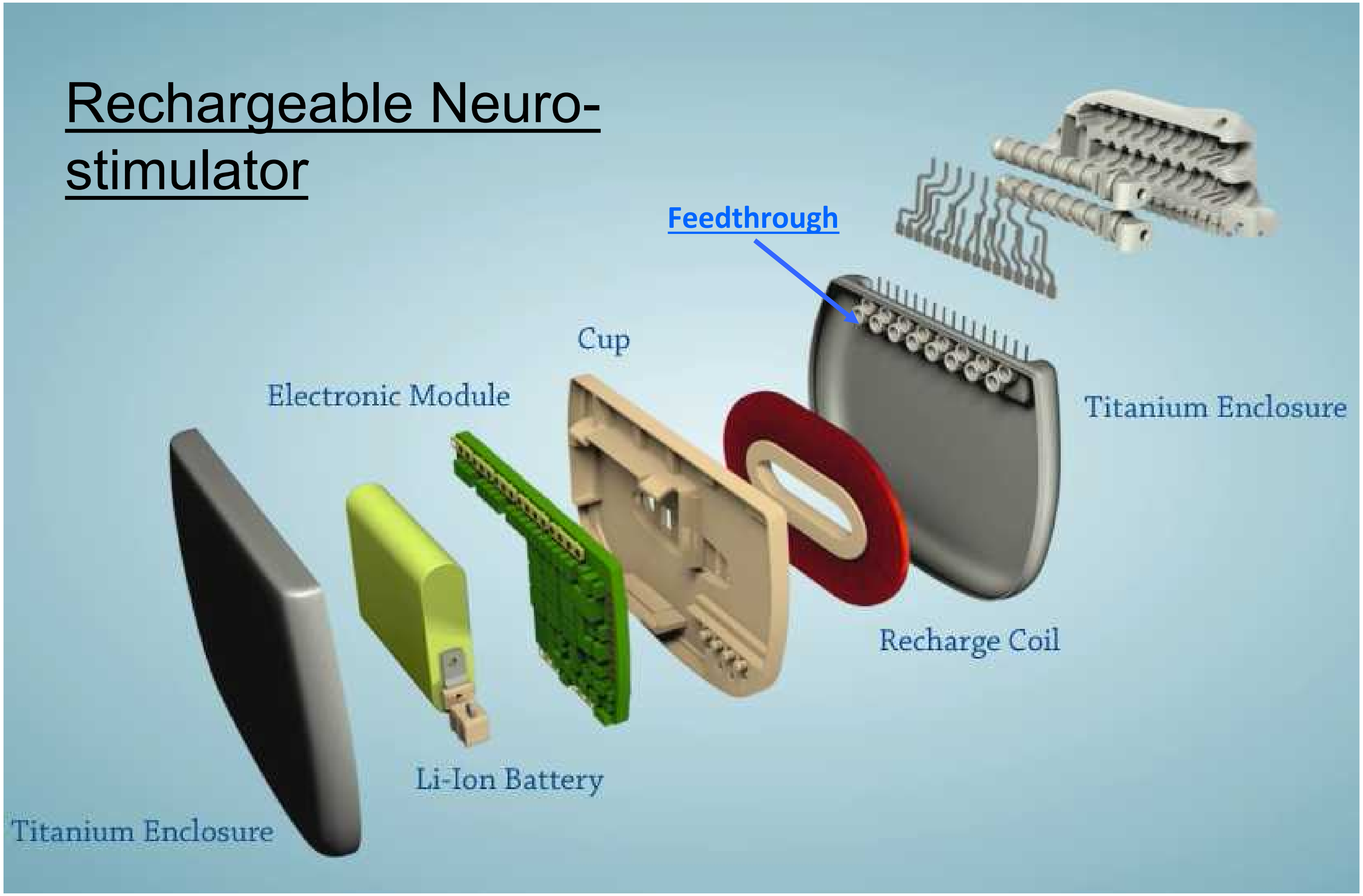
Tibial Fractures



* Not approved for commercial distribution in the United States
** Humanitarian Device in the United States – the effectiveness for this use has not been demonstrated

~70 B /per annum

# Implantable Medical Devices



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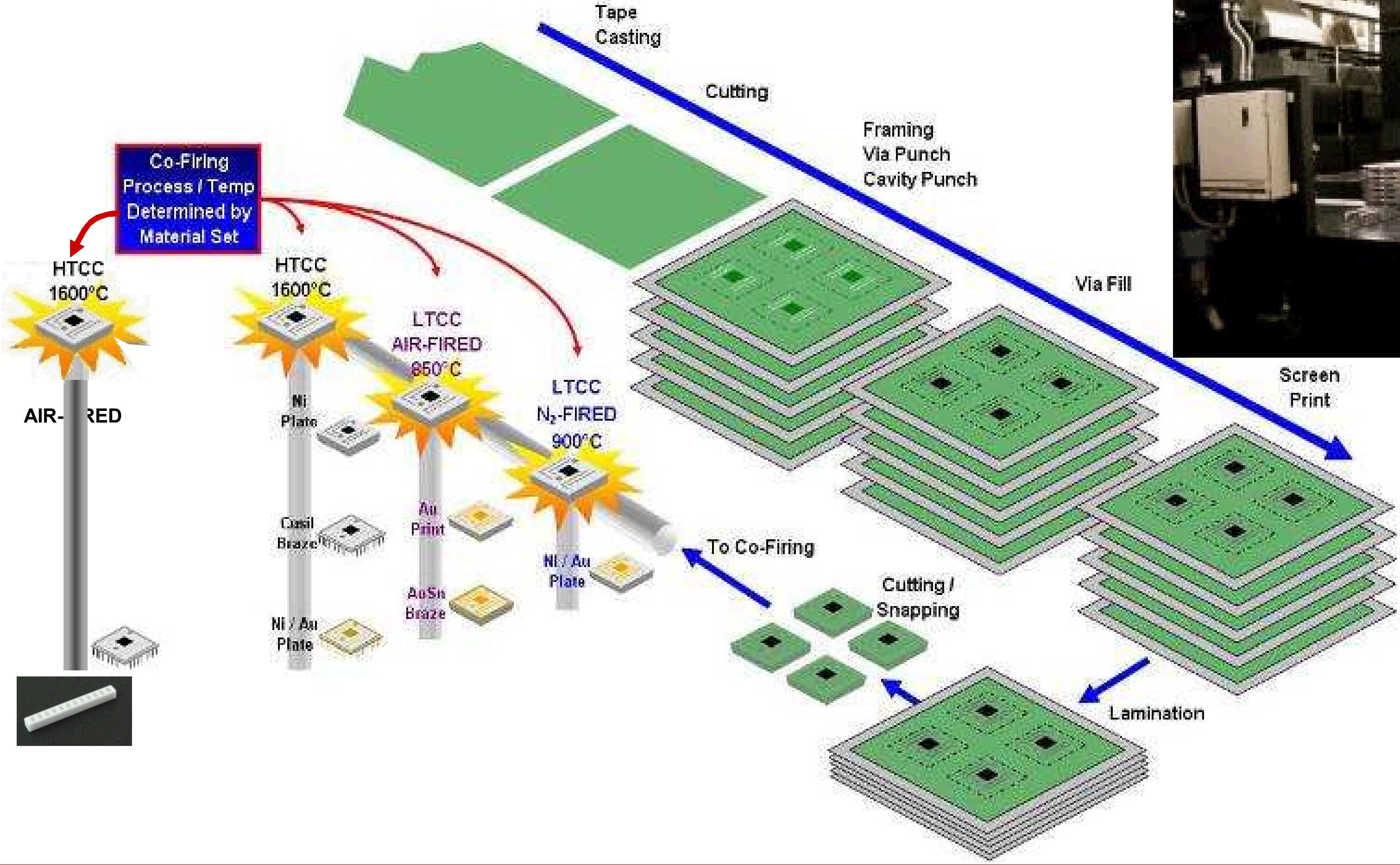
# High Temp. Co-fired Ceramics (HTCC)

## 90-96% Alumina: W, Mo, Pt, Au, Ag via High Temperature Sintering



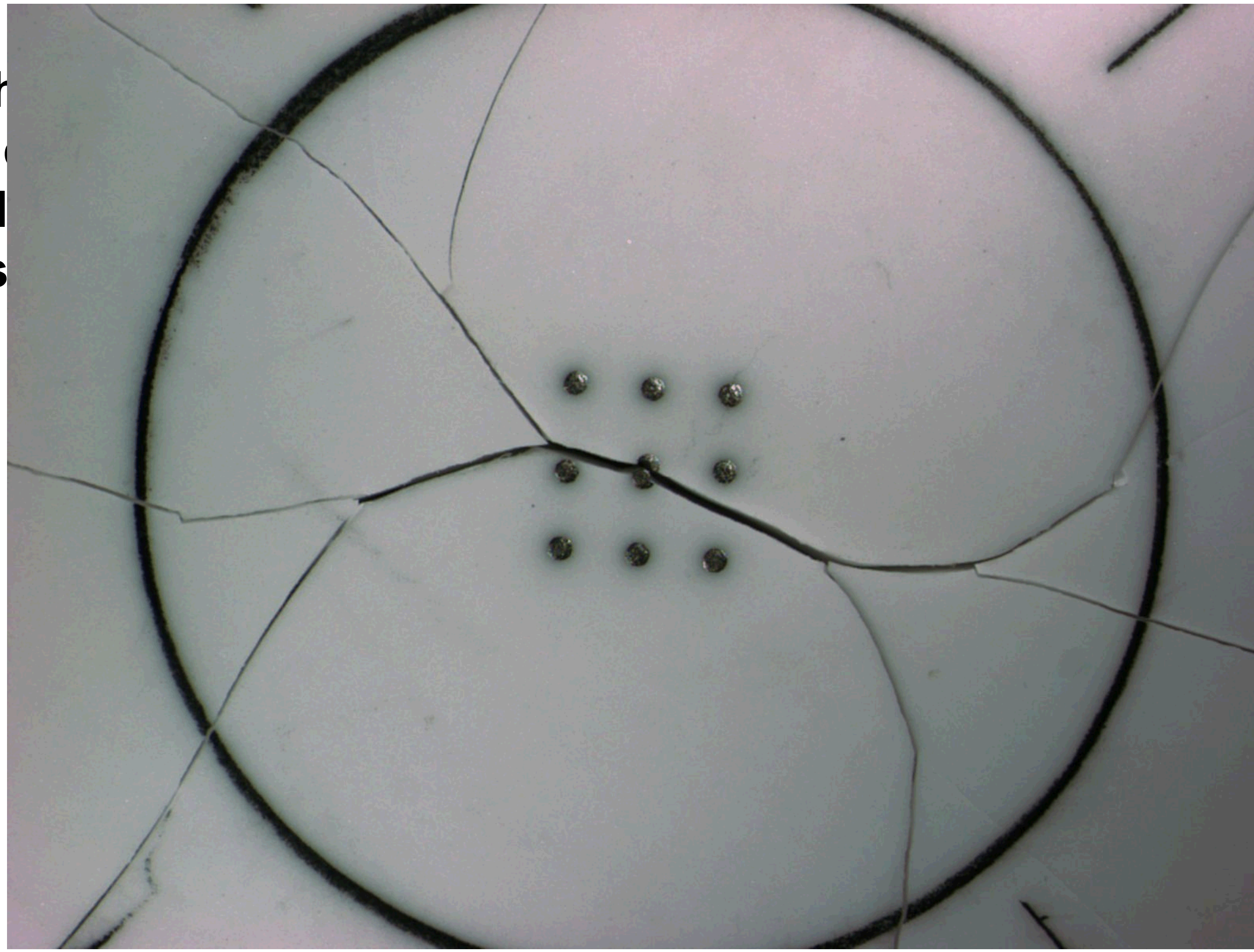

**HTCC Belt Furnaces**

# Hermetic Feedthroughs for Medical Devices

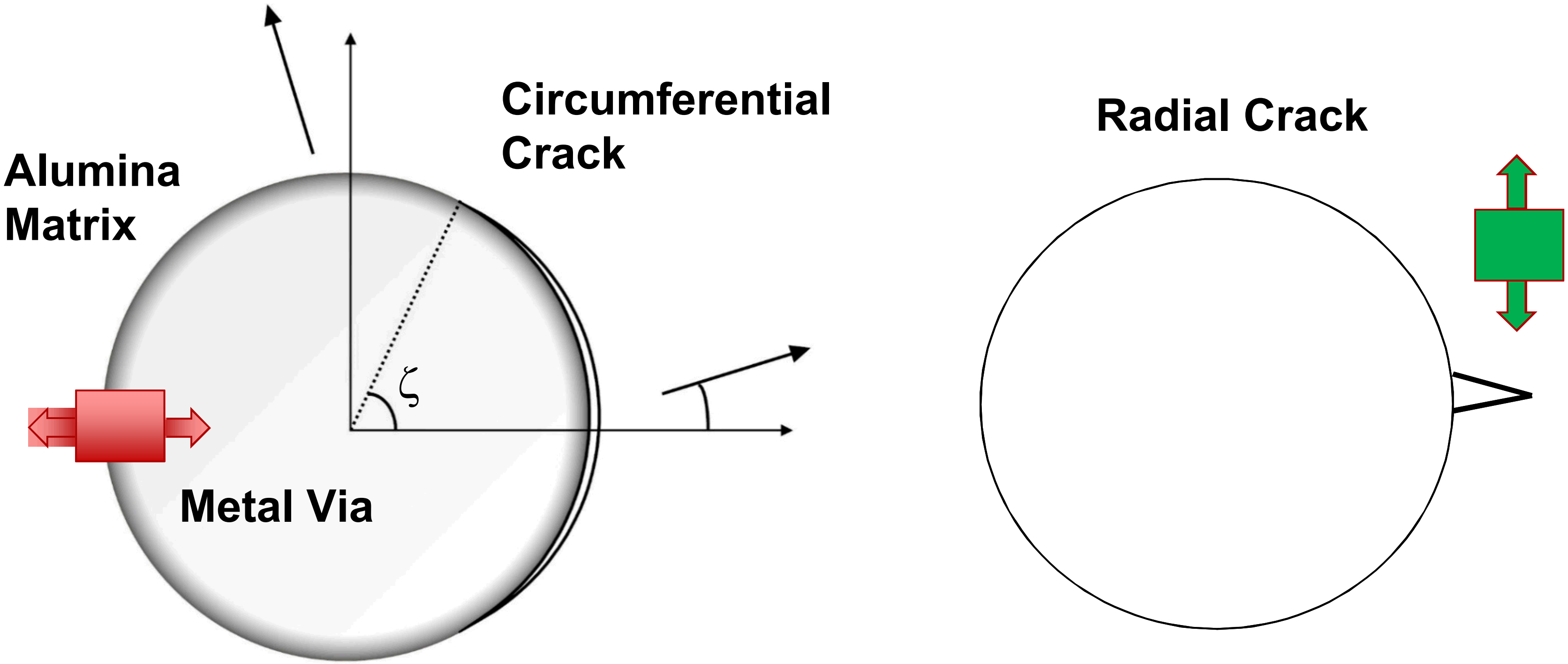
**Alumina - High Temperature Co-fired Ceramic (HTCC)**

Physical and electrical characteristics for high-reliability applications:

- **Mech**
- **High**
- **Easil**
- **Pass**
  - **ntennas**



# Stress State Around a Via Impacts Strength




**Local residual stress – Due to thermal and elastic mismatches, modified by plasticity of via material**

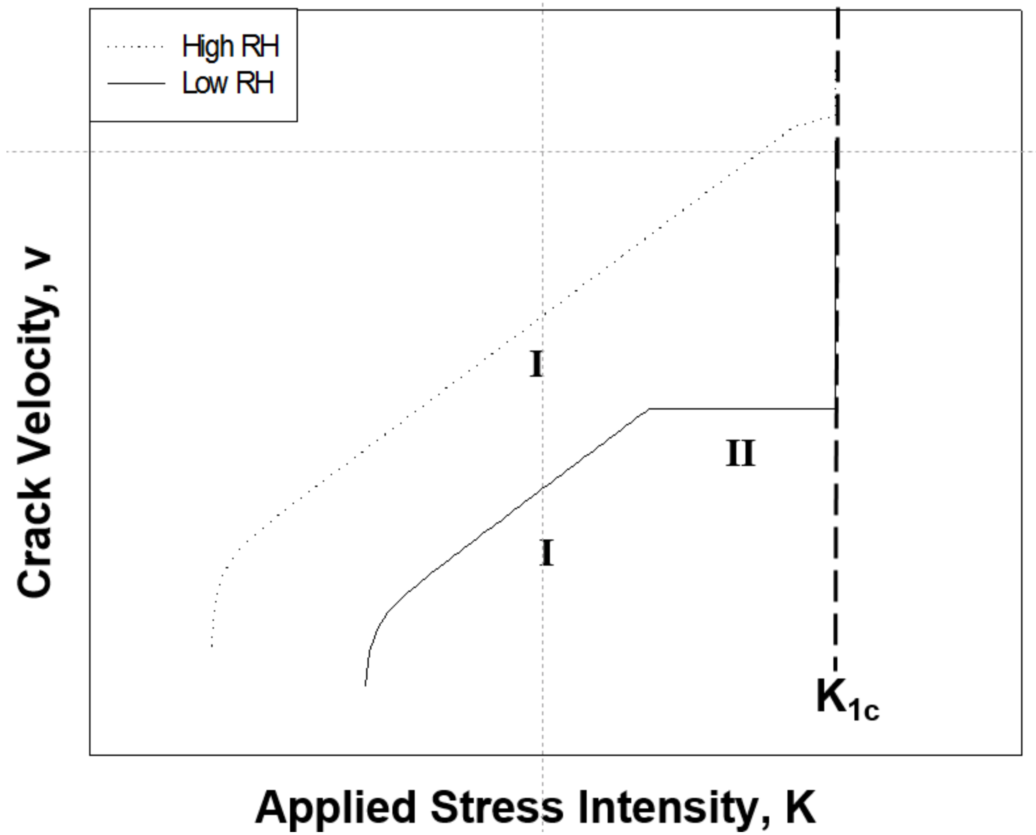
**Higher thermal expansion via**

**~Similar expansion via + plasticity**

**Externally applied stresses – Thermal transients, & due to brazing/welding of material**

**Combination of these stresses can lead to Sub-Critical Crack Growth (SCG): can cause leaks, crack growth and failure**

# Sub-Critical Crack Growth (SCG)



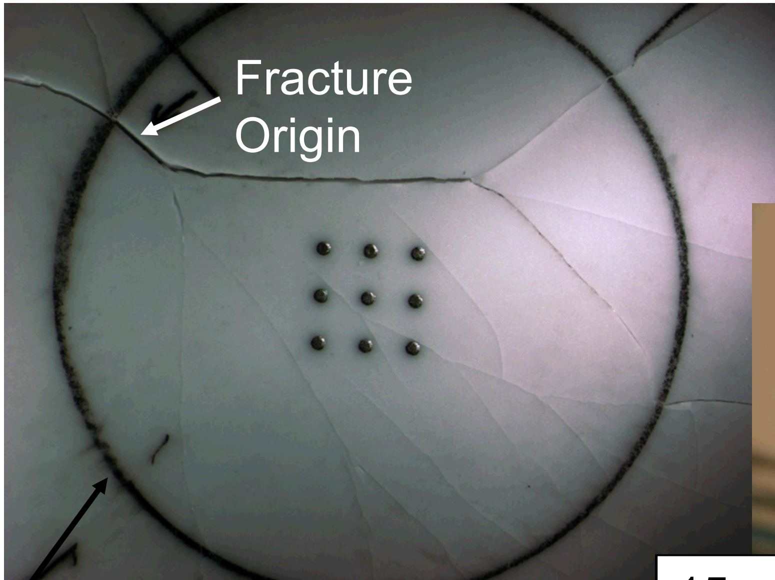

$$v = A\left(\frac{K_I}{K_{Ic}}\right)^n$$

**SCG behavior was quantified by conducting strength tests as a function of loading rates** *(ASTM C1368: Test method for SCG Paremeters)*

**Materials with and without vias were strength tested in 20% RH, and in 0.9% saline (simulated body fluid)***

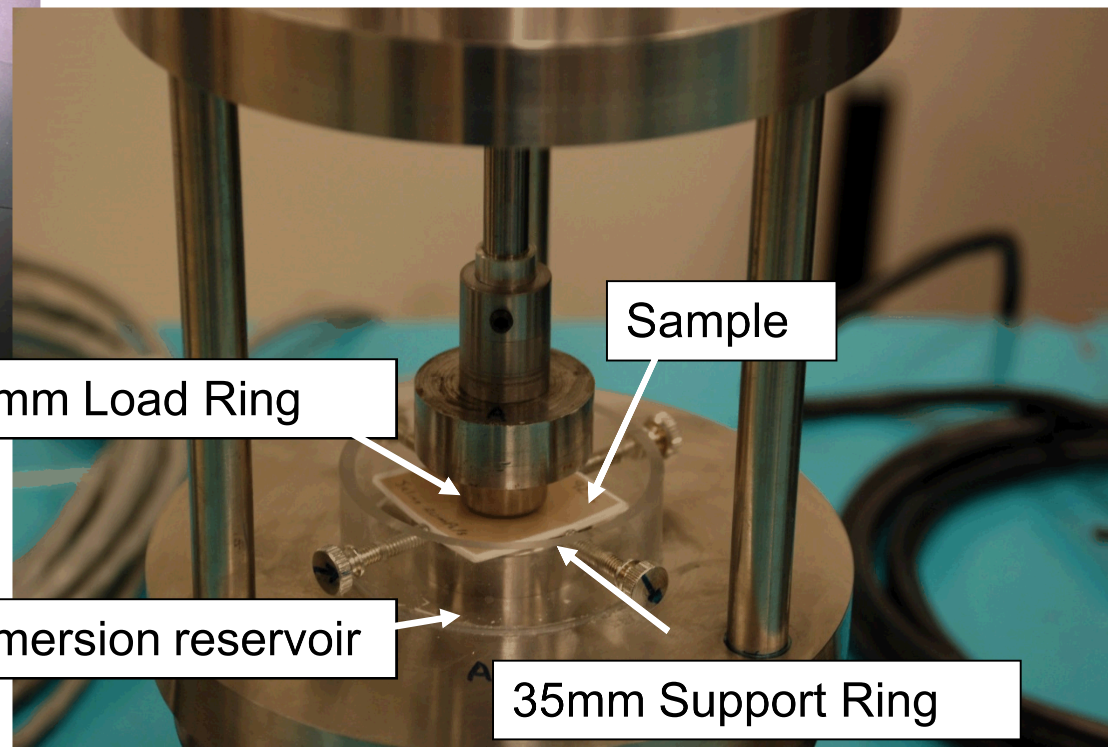
*https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3683025/

# Reliability of Devices




Tensile region
(inside black circle)

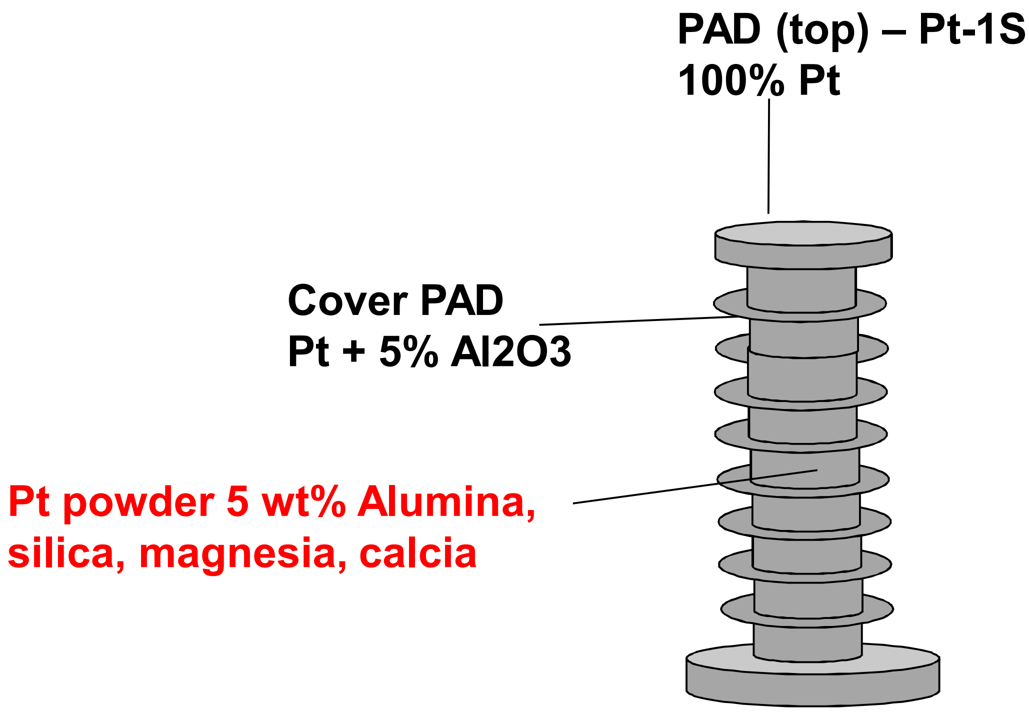
*(ASTM C1368 strength testing*




**Sample Size: 40mm$^2$ x 2mm**

Loading rings made of Tefzel material

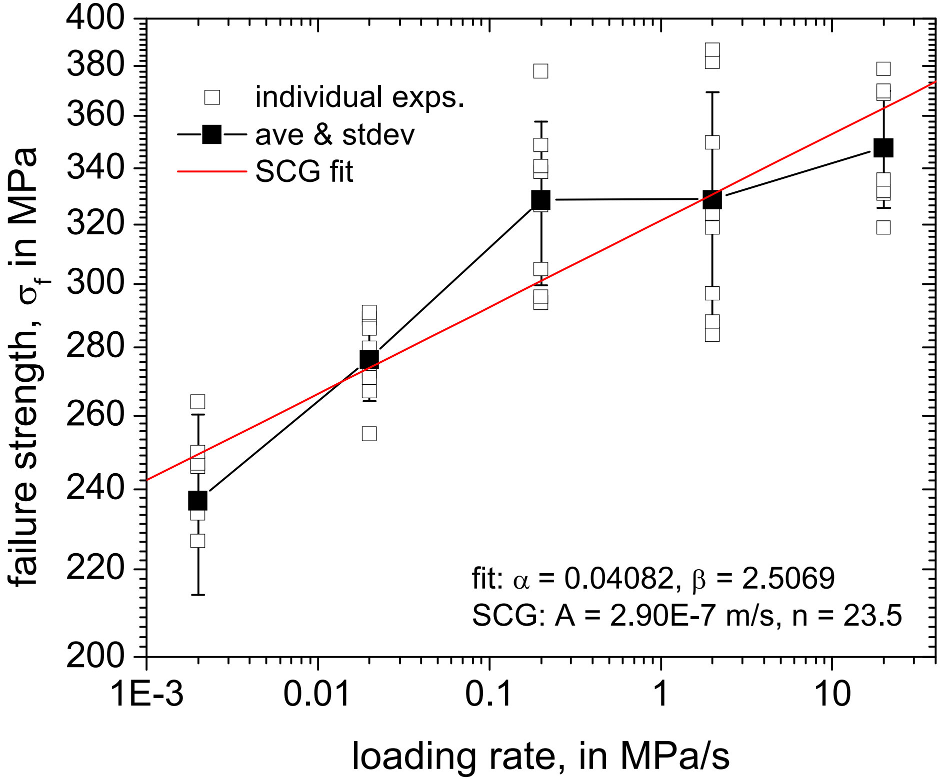
# Phase I: Via Materials Composition



# Phase I – 20% RH Air

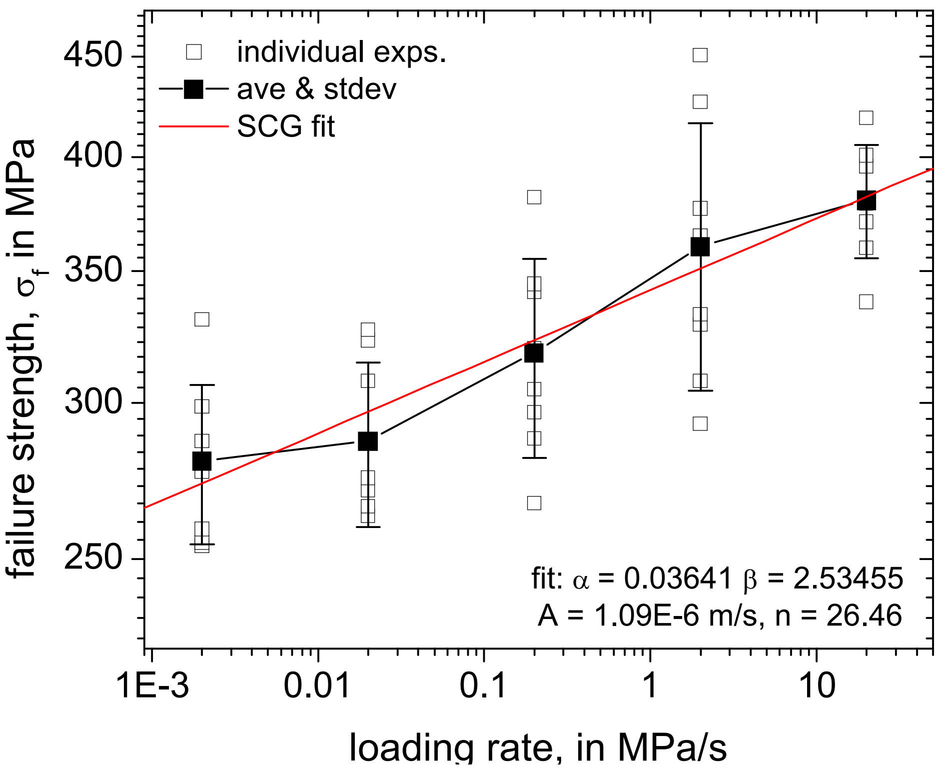
$$v = A\left(\frac{K_I}{K_{Ic}}\right)^n$$

### No Vias- Base 92% Alumina




**n=26.9, A=2.08*10^-7 m/s**

### Alumina with Vias

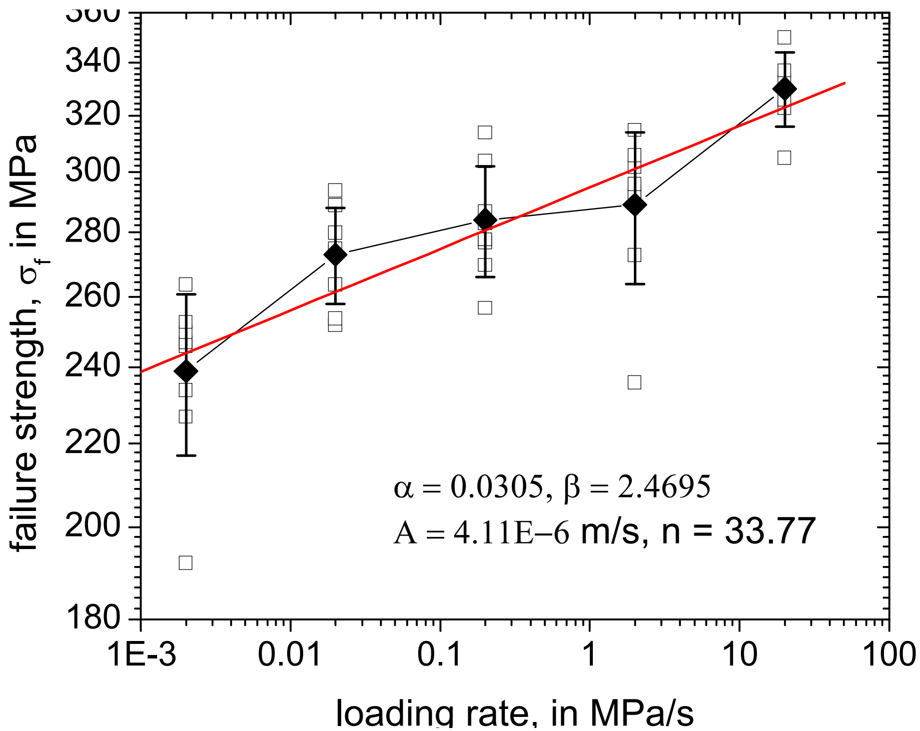



**n=26.3, A=5.6*10^-7 m/s**

**n values ~ those of alumina in literature**
**Strength Response in air is not affected by vias**

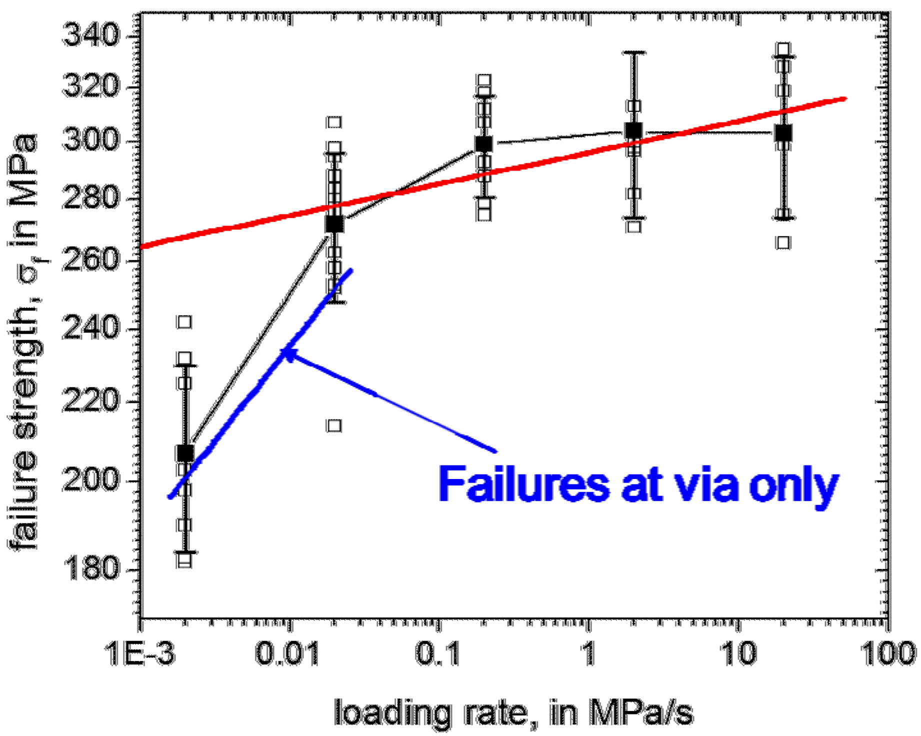
# Phase I- Saline Immersion *(in vivo simulation)*

**No Vias- Base 92% Alumina**




**n=36.7, A=4.54*10$^{-6}$ m/s**

**Alumina with Vias**



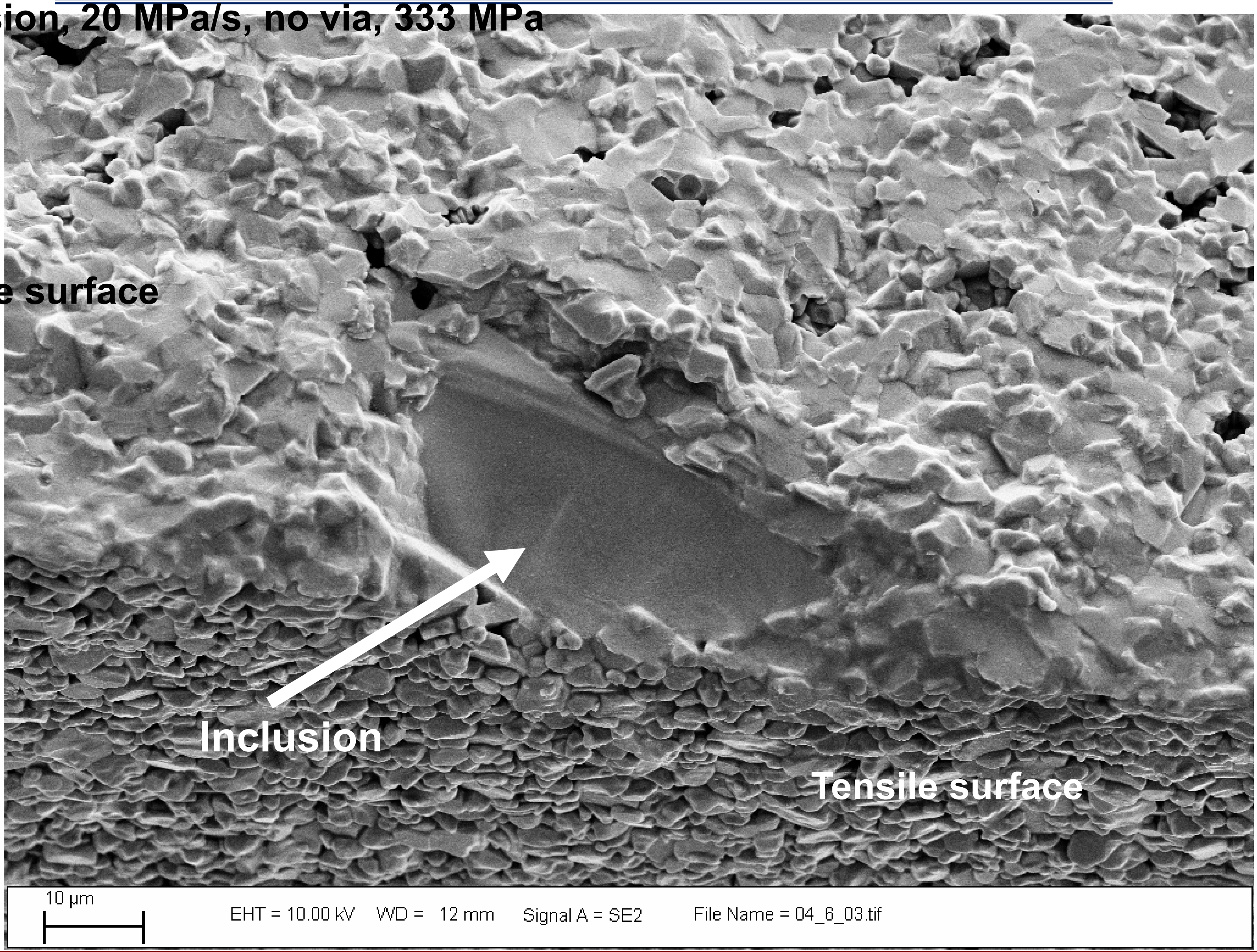

**n=38.1,A=5.07*10$^{-8}$ m/s**

**At Via n=9.2, A=1.0*10$^{-8}$ m/s**

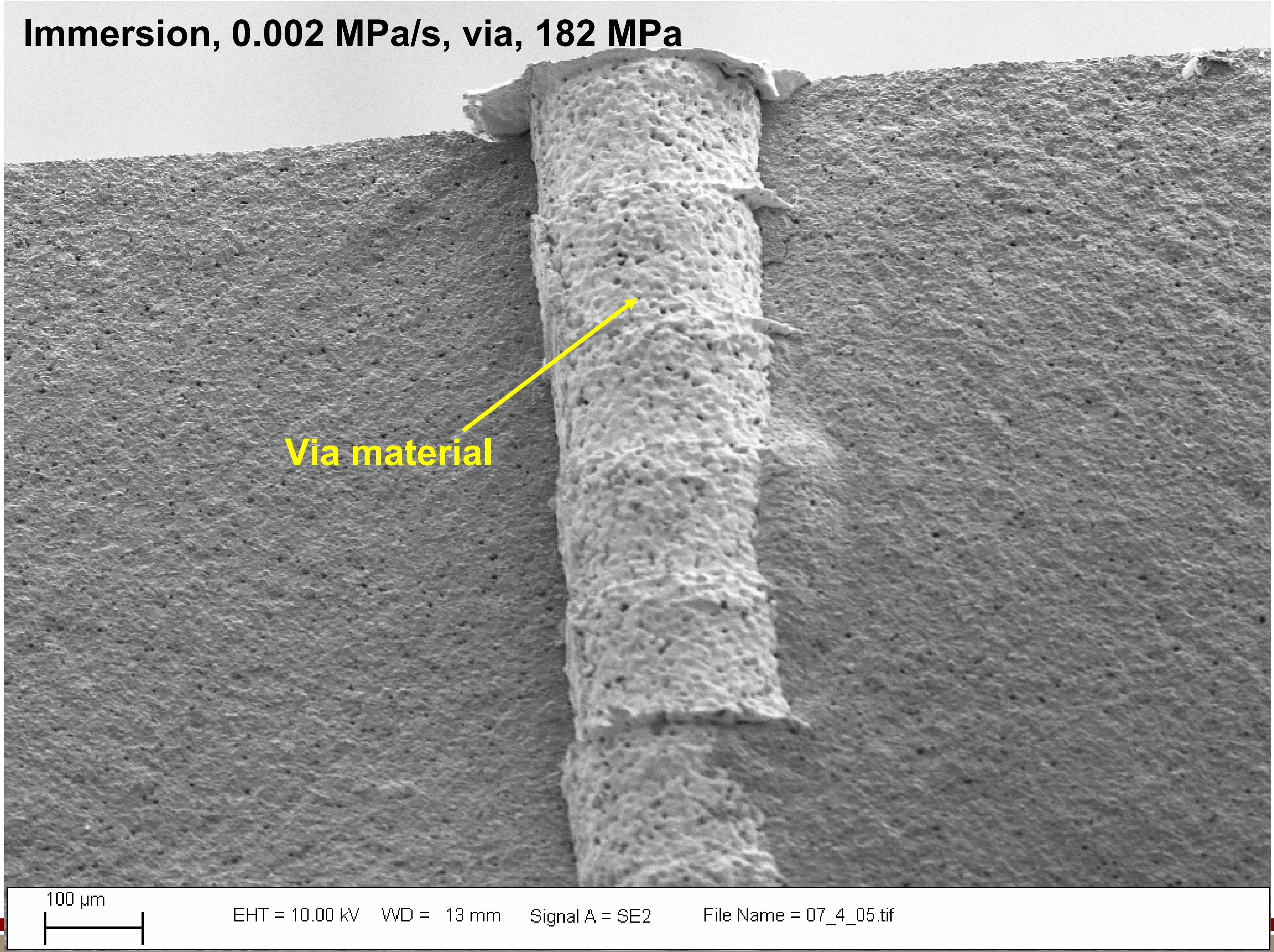
**Vulnerability: Slow rates and saline environment**

# Fractography- Hard Inclusion

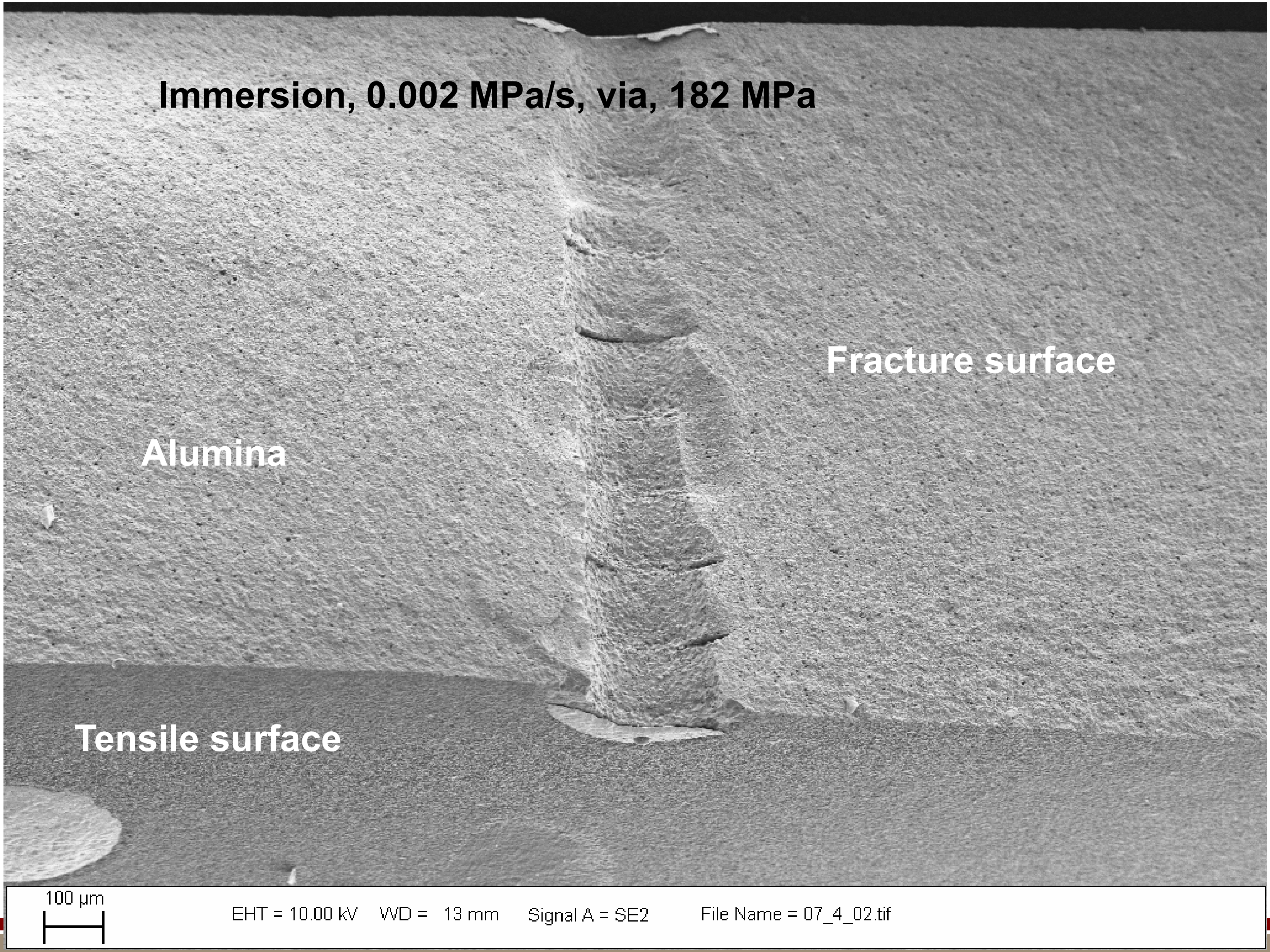
Immersion, 20 MPa/s, no via, 333 MPa



# Fractography – Via Separation - A

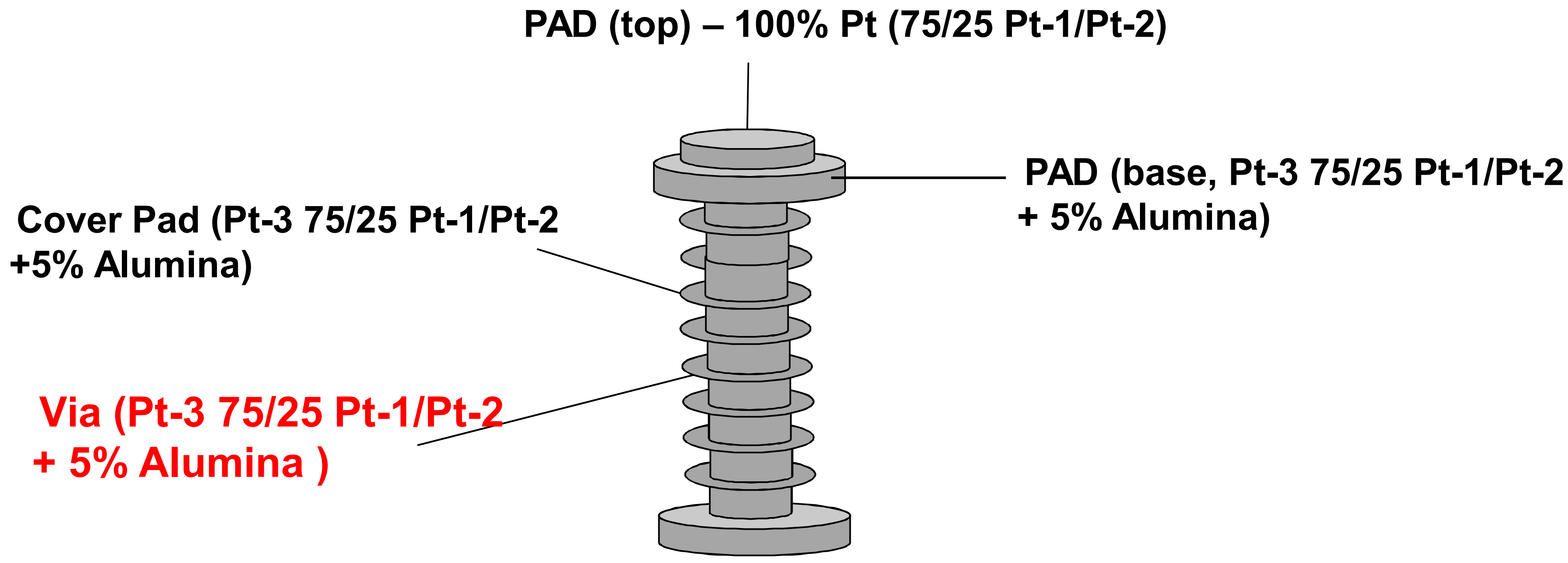


# Fractography – Via Separation - B



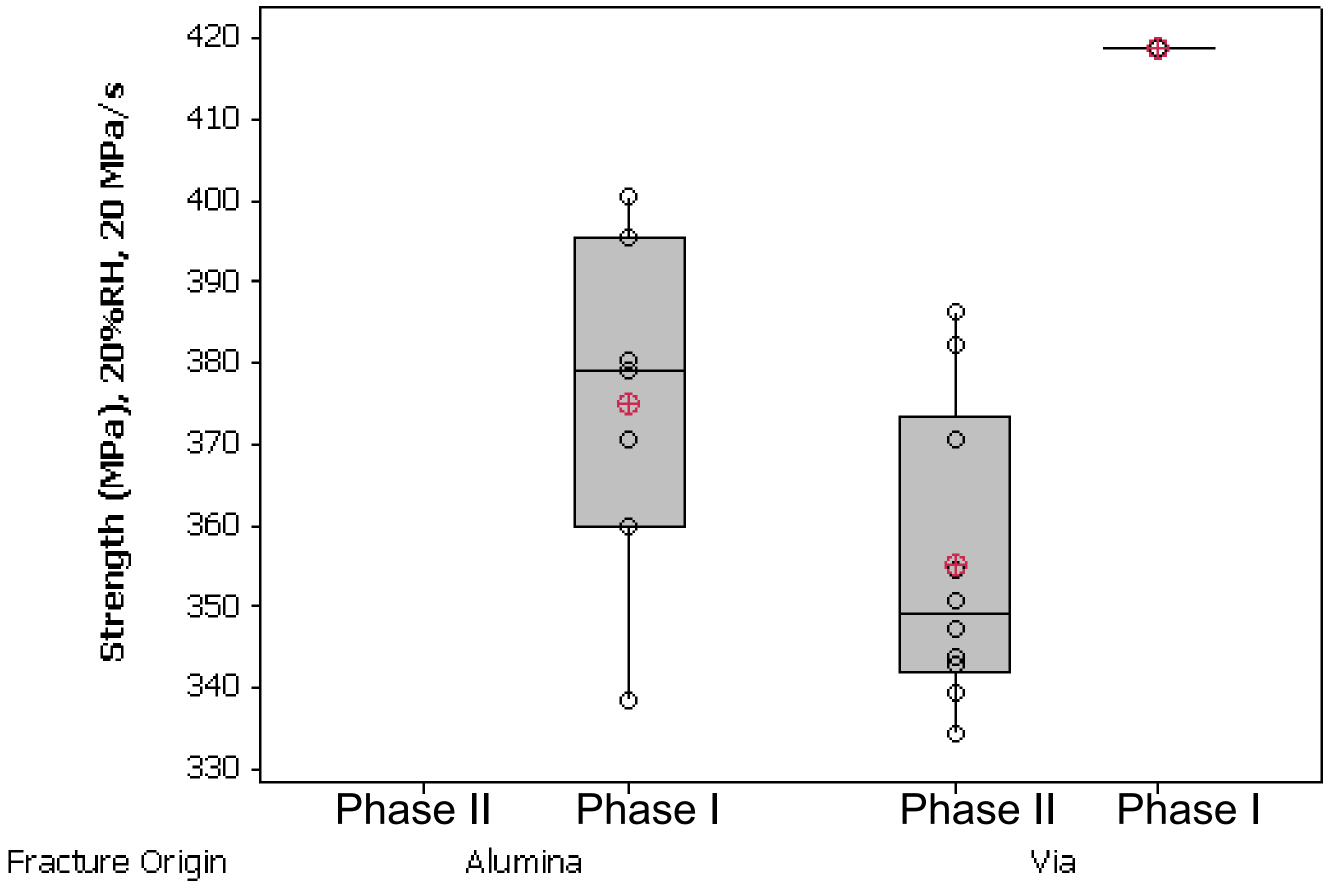
# Phase II

Significant modification to
process to improve via interfaces



# Phase II – 20% RH, Alumina with Via

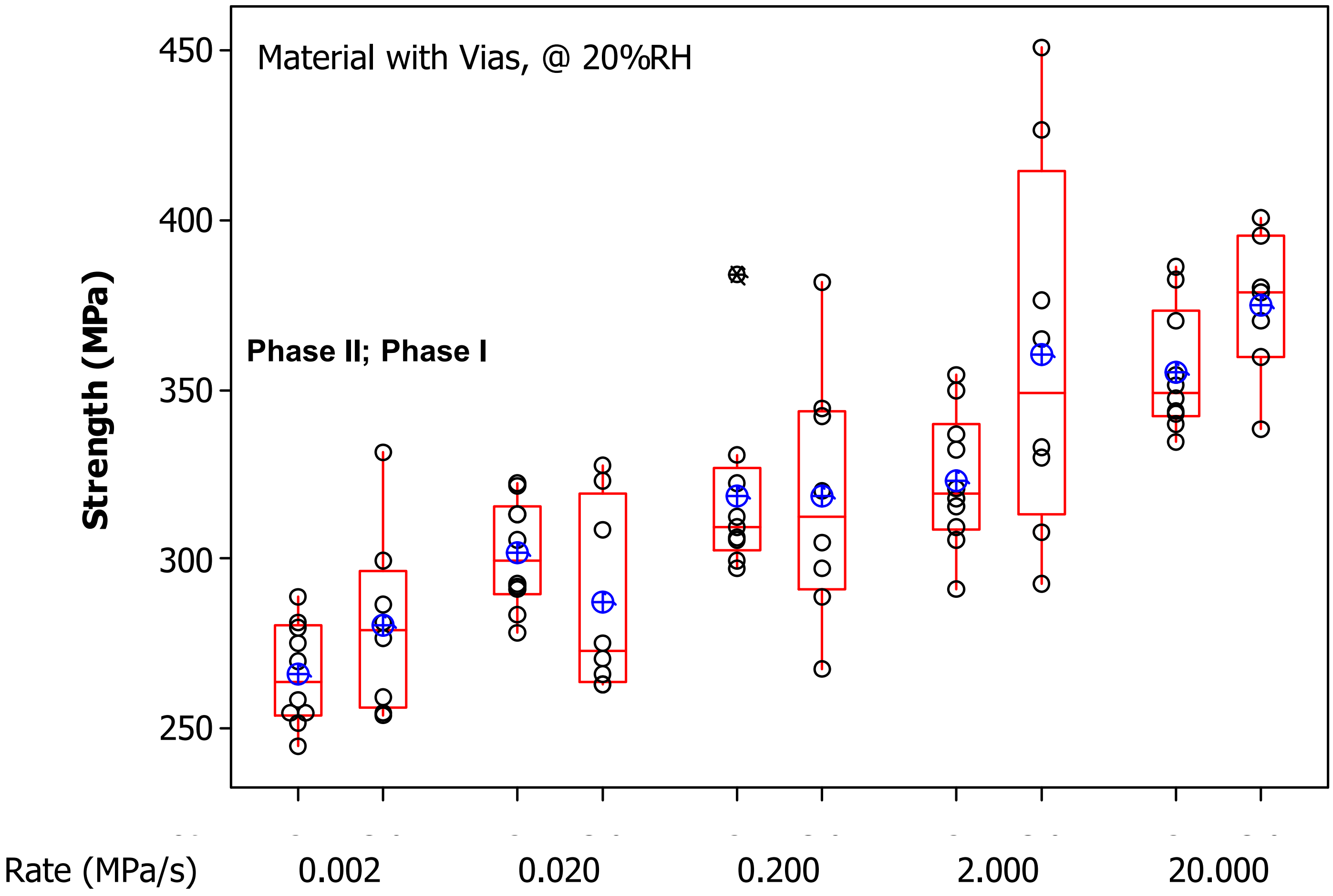
Fast testing rates (20 MPa/s), and 20% RH




The new batch of samples have lower mean strength.

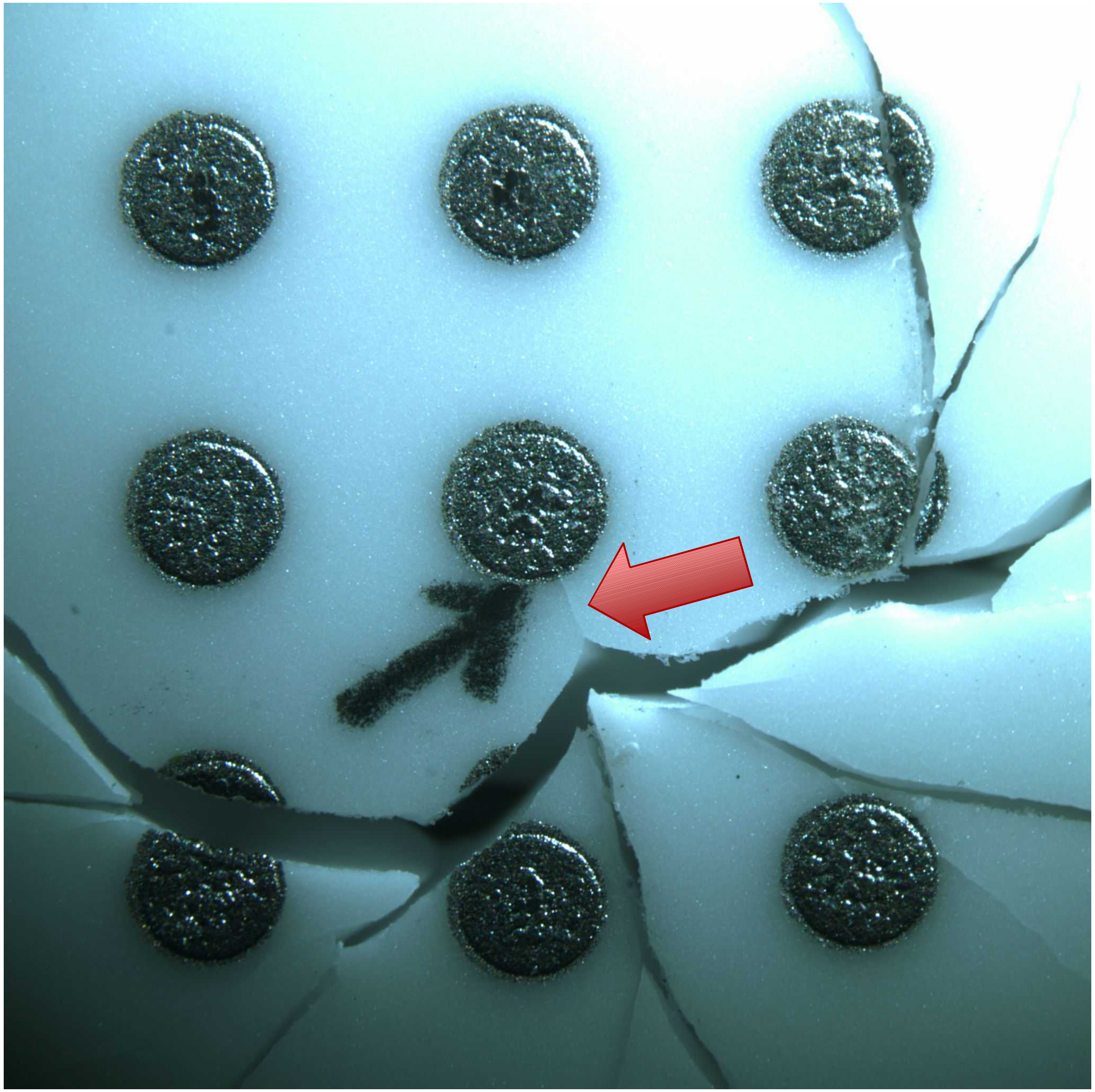
**The failure origin has shifted: All failures are from the via**

# Phase II – Strength Lower

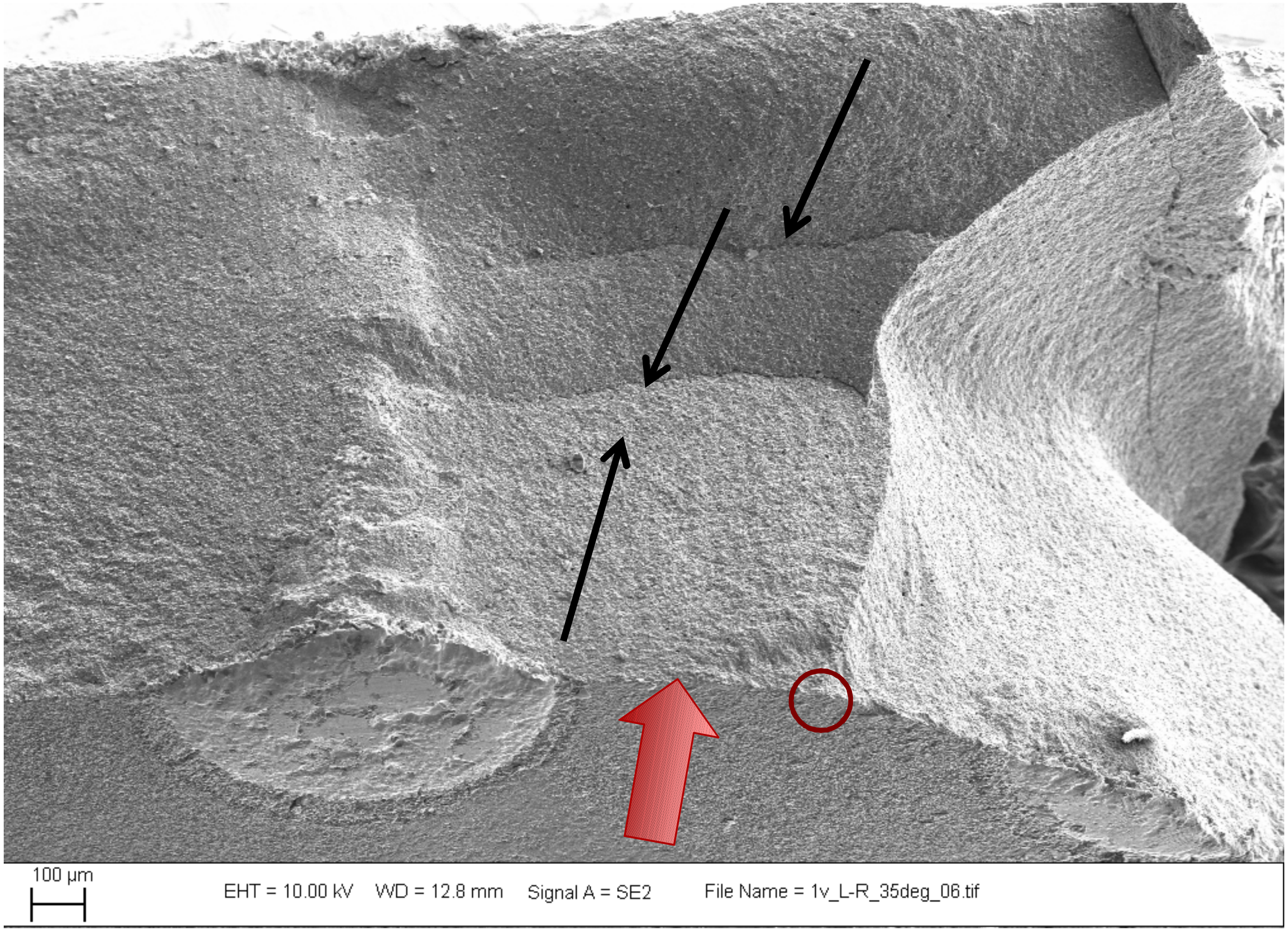


# Phase II – Fractography (radial cracks)

Via 20 MPa/s
20% RH



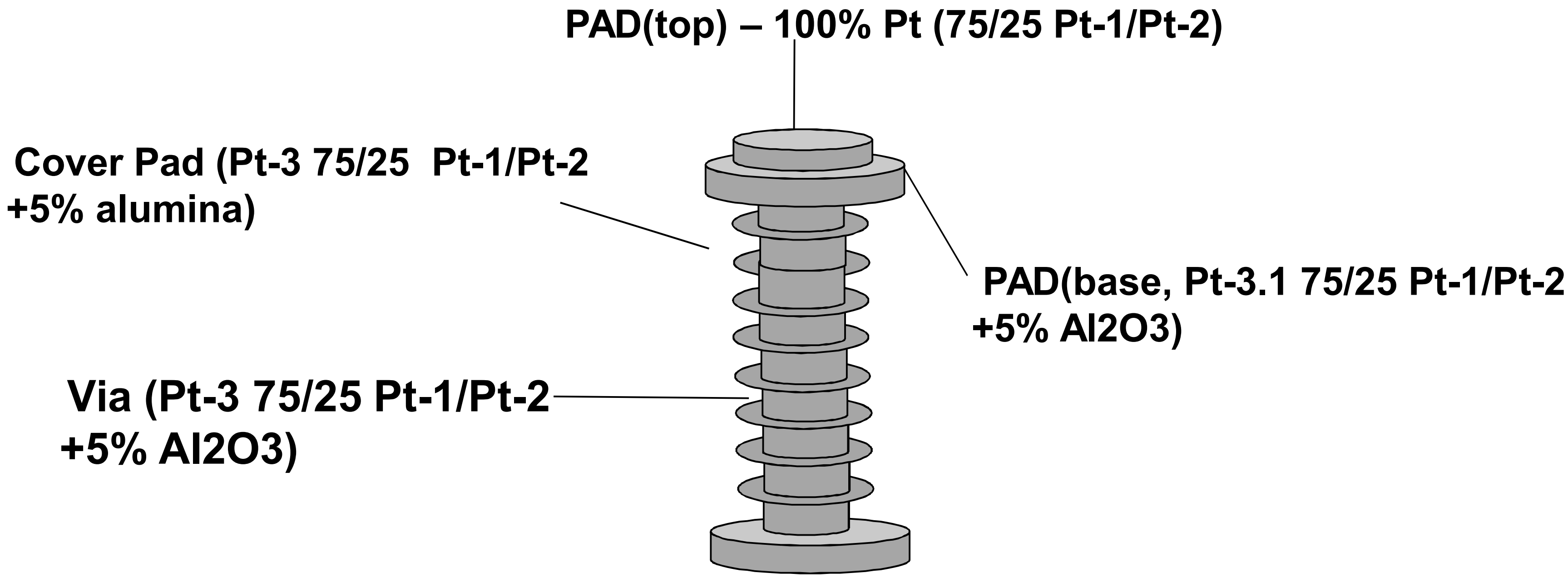
# Phase II – Fractography (radial cracks)



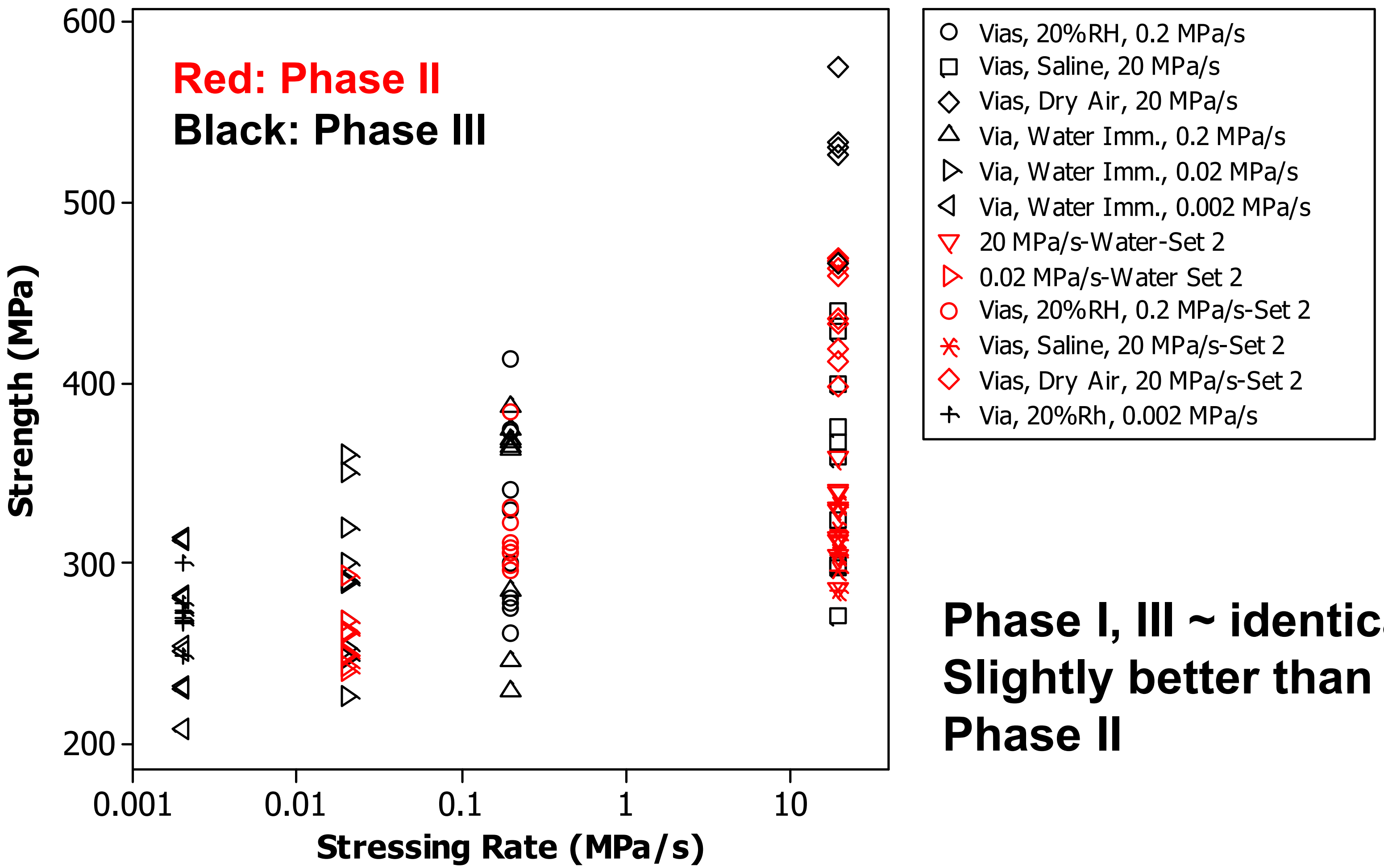

**These samples must have a small circumferential tensile stress near the vias: Radial cracks and slightly lower strength**
**Lamination ?**

# Phase III

Modification of Pt ratios in pastes
Modified paste solvent vehicle
Changed lamination procedure

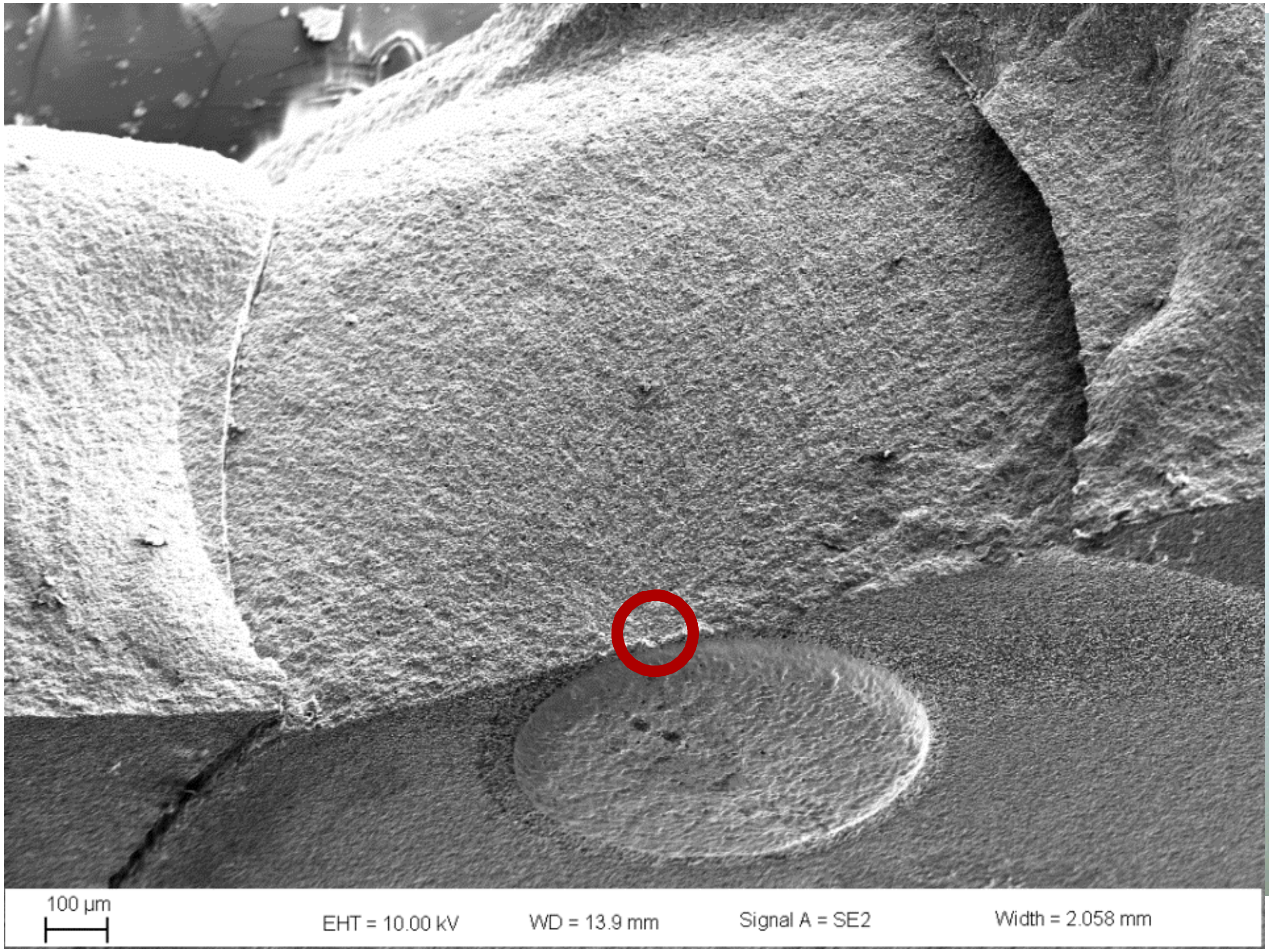


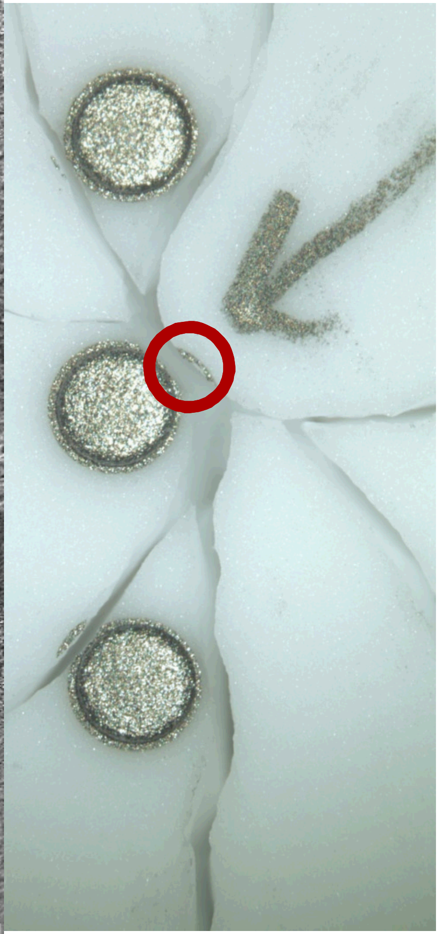
# Phase III – Strength ~ base alumina




**Phase I, III ~ identical**
**Slightly better than Phase II**

# Phase III - Fractography



# Conclusions

**Strength:**

Materials in Phase I, III had ~ identical strength; Phase II slightly lower

**Notable exception of saline immersion, Phase I**

- Vulnerability must be considered, tested for, and designed out prior to use

**Stress State around the via (plasticity and thermal expansion considerations):**

Phase I has a slight radial tension, and failure along interface in depth

- Removal of higher expansion glass phase led to redress of interfacial failure mode

Phase II has a slight circumferential tension, and radial cracking

Phase III has ~ 0 radial tensile stress

**Lifetime:**

Parameters extracted from these tests, and stresses use geometry, were used to calculate lifetimes > 20 years

**Overall:**

**We can obtain material with vias that have similar lifetimes as base alumina material.**

Title: Failure analysis and sub-critical crack growth (SCG) characterization of Pt-$Al_2O_3$ high temperature co-fired (HTCC) ceramics

Abstract: Miniaturization and integration of multiple functions into one component is desired for device downsizing. HTCC alumina, with its high strength and bio-compatibility, provides an option for integration and higher reliability medical devices. A 92% alumina-platinum via HTCC material was characterized for failure modes and sub-critical crack growth, and modifications to processing were implemented to obtain a material with strength and SCG characteristics similar to bulk alumina. In phase I development, this material had strength equivalent to bulk alumina, except at low stressing rates in saline, body fluid-like environments, where a novel failure mode (circumferential cracking) was encountered. Processing changes implemented for Phase II materials led to failures emanating as radial cracks from the vias with slight loss of strength. Changes made to Phase III materials led to strength and SCG characteristics that were undistinguishable from the base materials. Fractographic evidence indicates that cracking originates tangentially to the via in Phase III material

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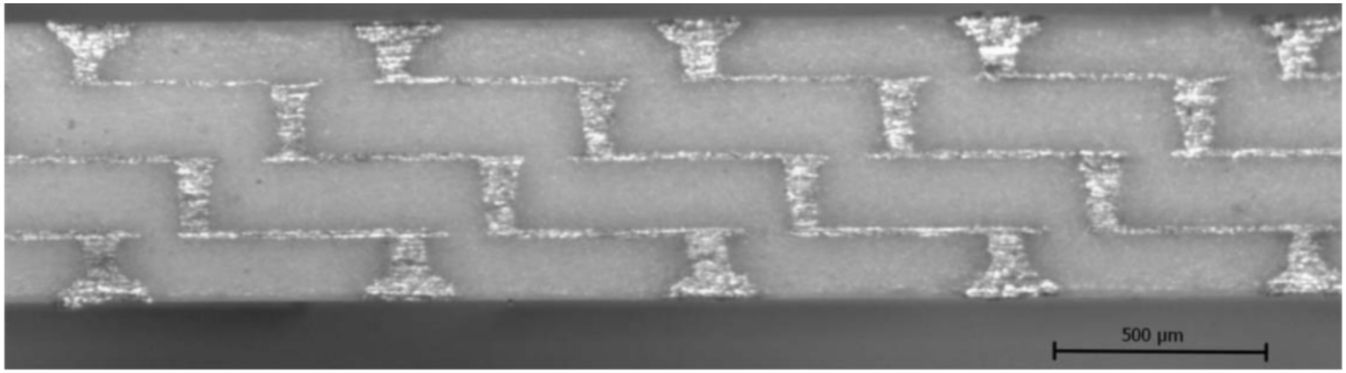
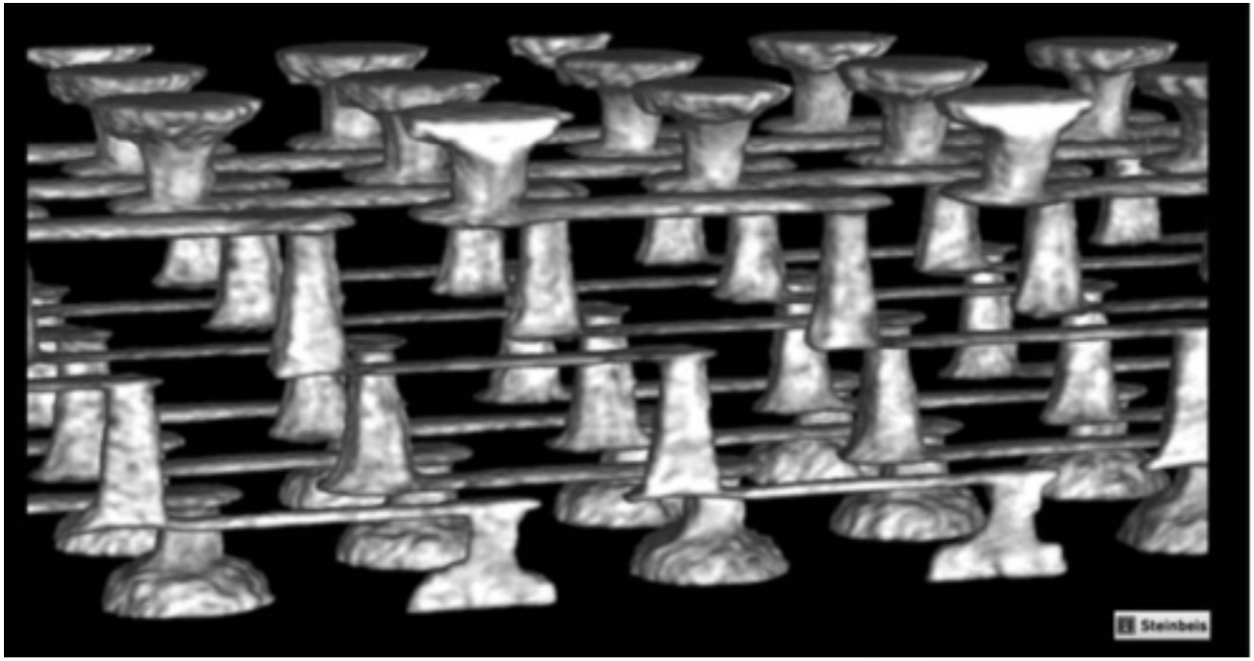
Authors: Rajan Tandon, Clay S. Newton (Sandia), Andy Thom, Joyce Yamamoto, Markus Reiterer, and Gordon Munns (Medtronic); Hidekazu Otomaru, Hiroshi Matsumoto, Kengo Morioka, and Arne Knudsen, Kyocera North America Inc.

# Via Geometry, Layouts




Guenther et al., Journal of
Biomedical Materials Research, 2013

DOI: 10.1002/jbm.b.33027