NASA MFC Piezocomposites:

A Development History

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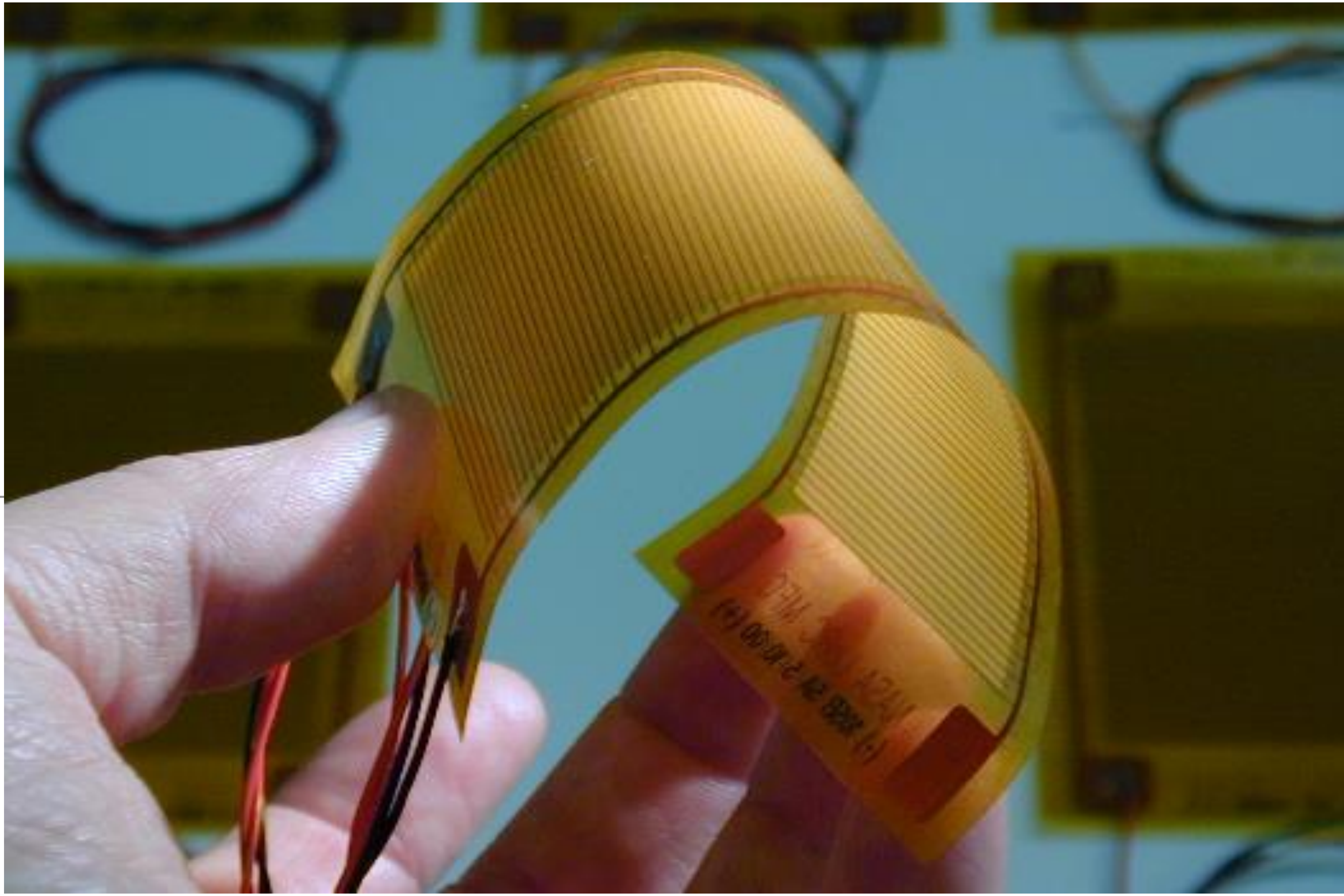
NASA Macro-Fiber Composite Actuator (MFC)



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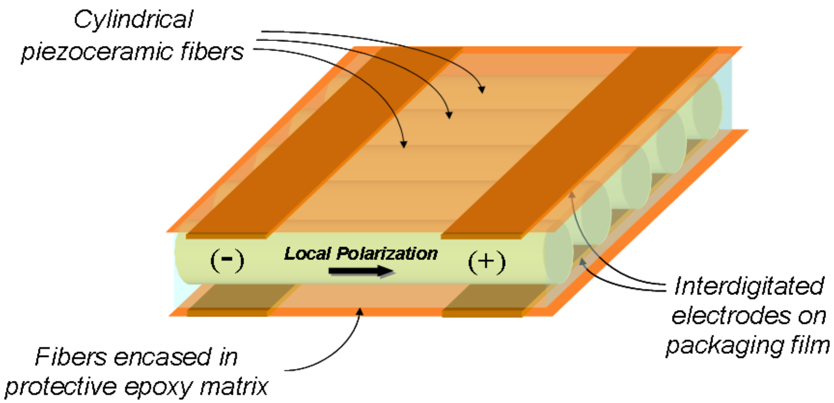
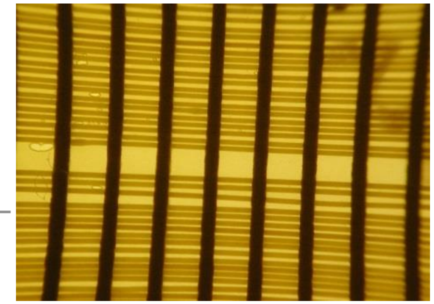
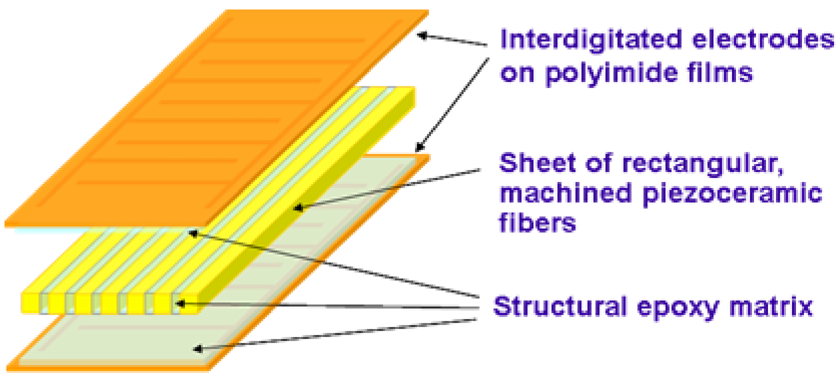
Structural Piezocomposite Actuator Evolution

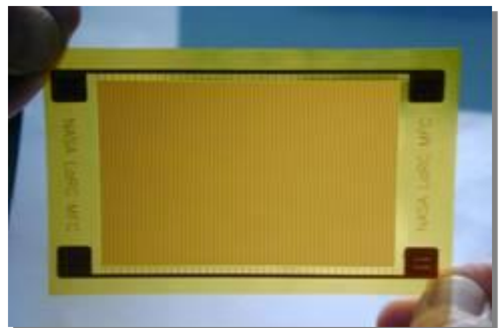


irregular construction

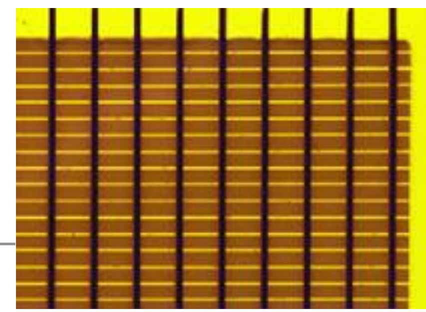


1st generation device: AFC (MIT, 1993-2000)





precision construction



Advanced piezocomposite: MFC (NASA, ARL, 1997-2003)

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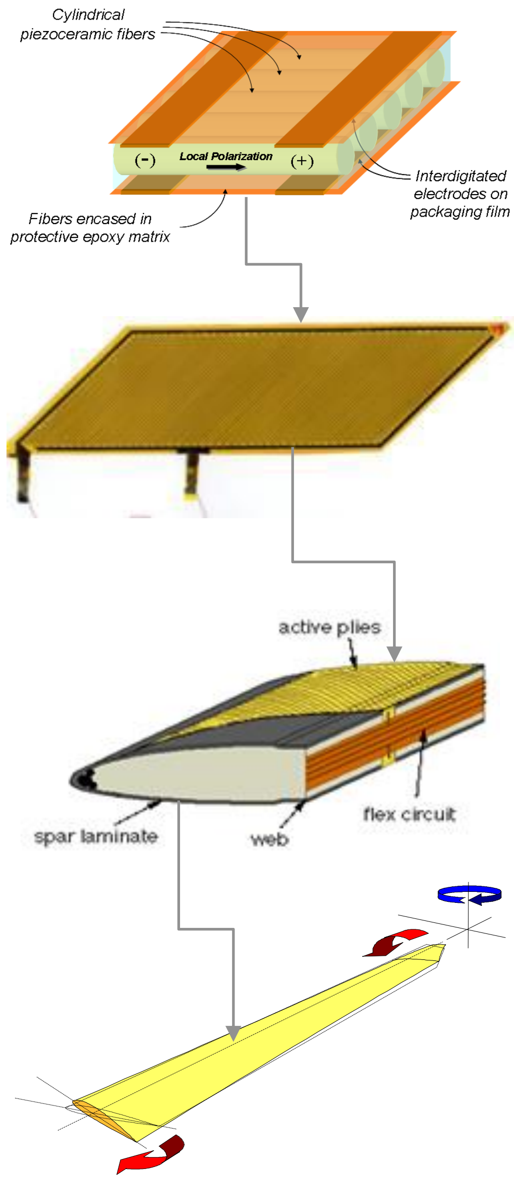
Active Blade Twist Control for Rotorcraft Vibration Reduction

1. Piezoelectric Composite Actuator

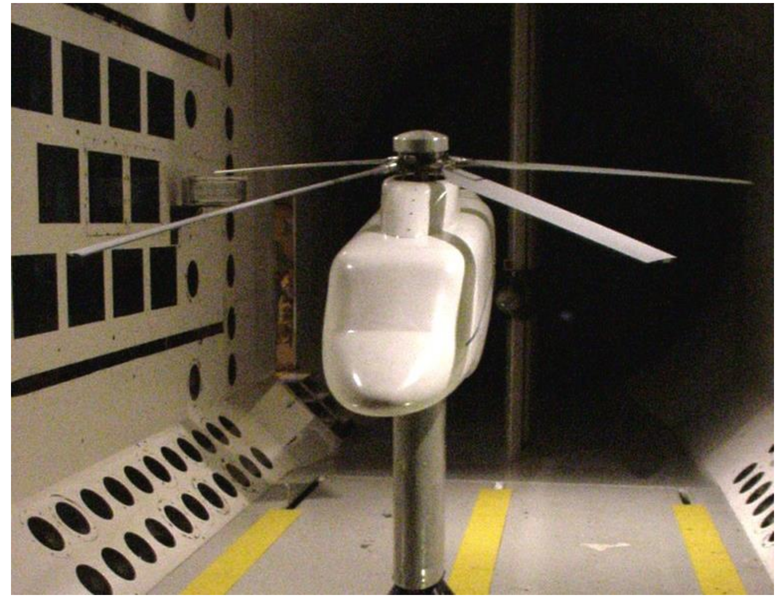
2. Active Fiber Composite Plies

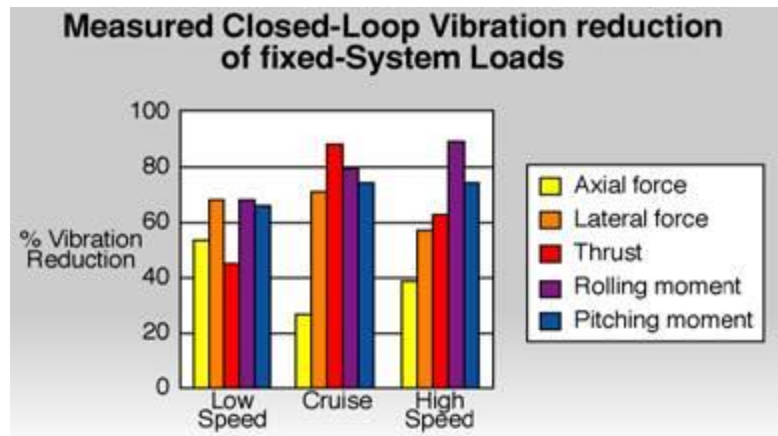
3. Active Composite Structure

4. Active Twist Control



4. Active Twist Rotor In Wind Tunnel





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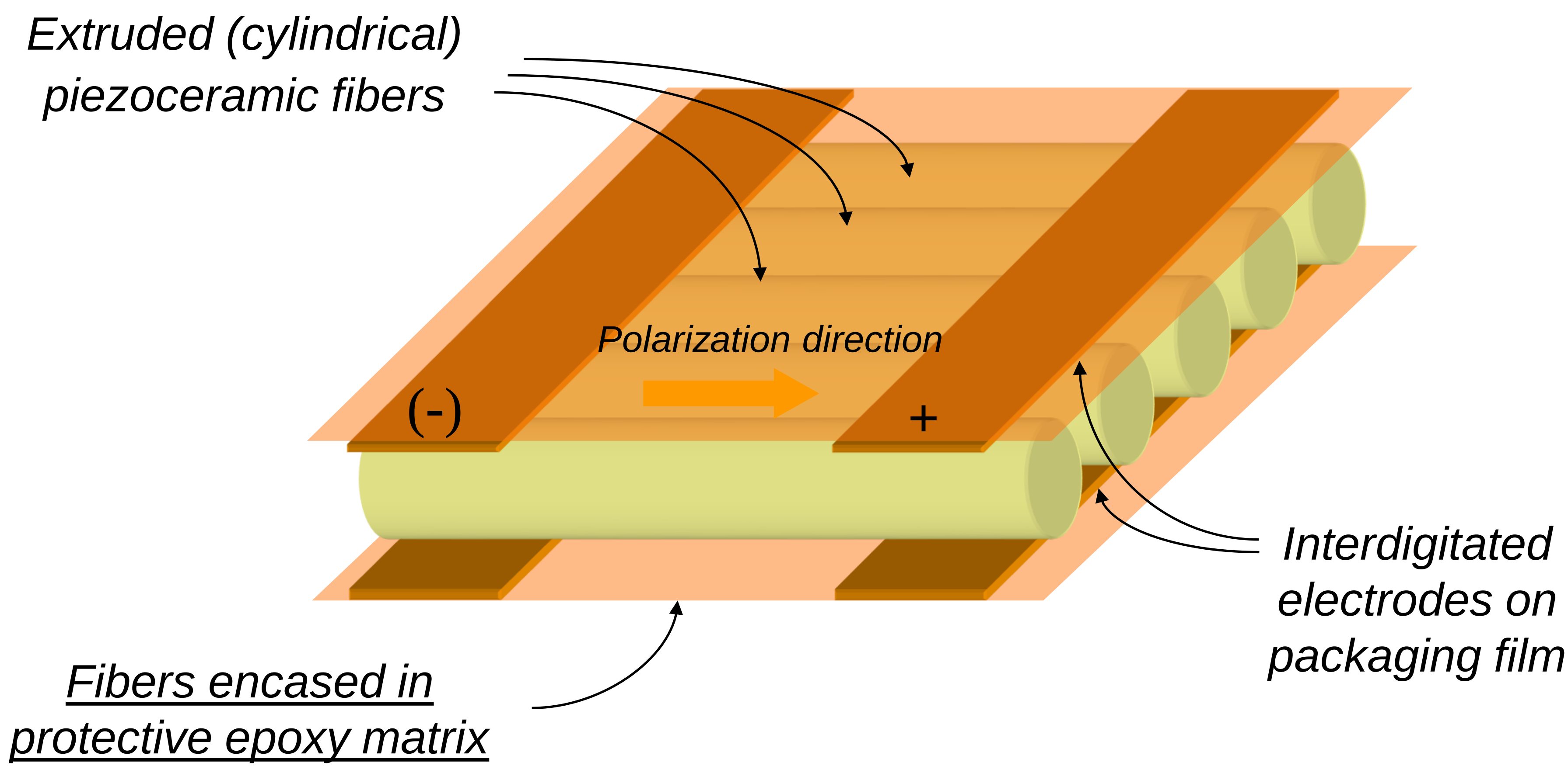
"Active Fiber Composite" (AFC) Concept

(MIT, 1995)



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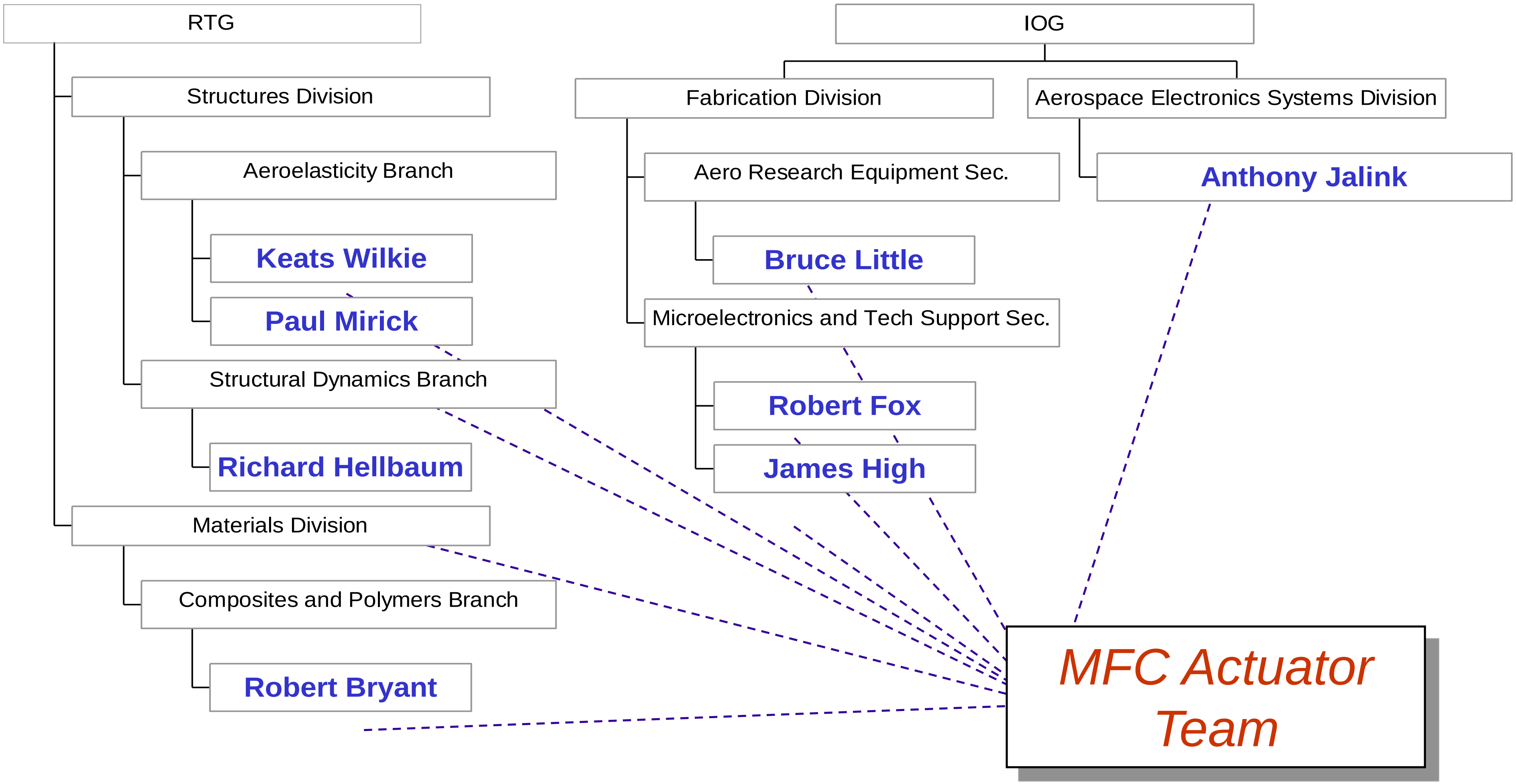
MFC Actuator Design Team



NASA Langley Research Center (LaRC), ca. December 1997

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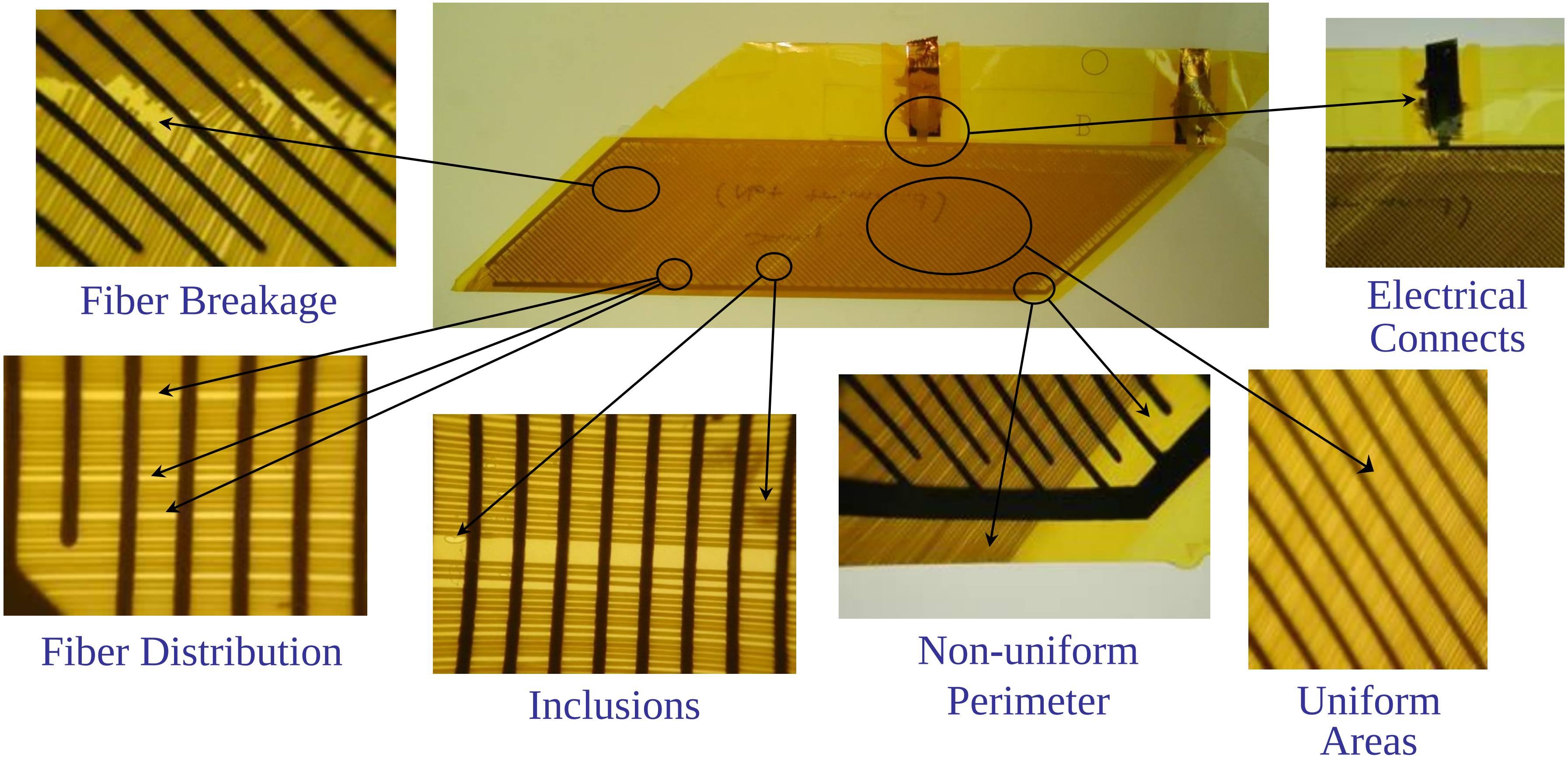
AFC Hand-Layup Quality Control Issues



Leads to a Wide Variance in Electro-Mechanical Properties

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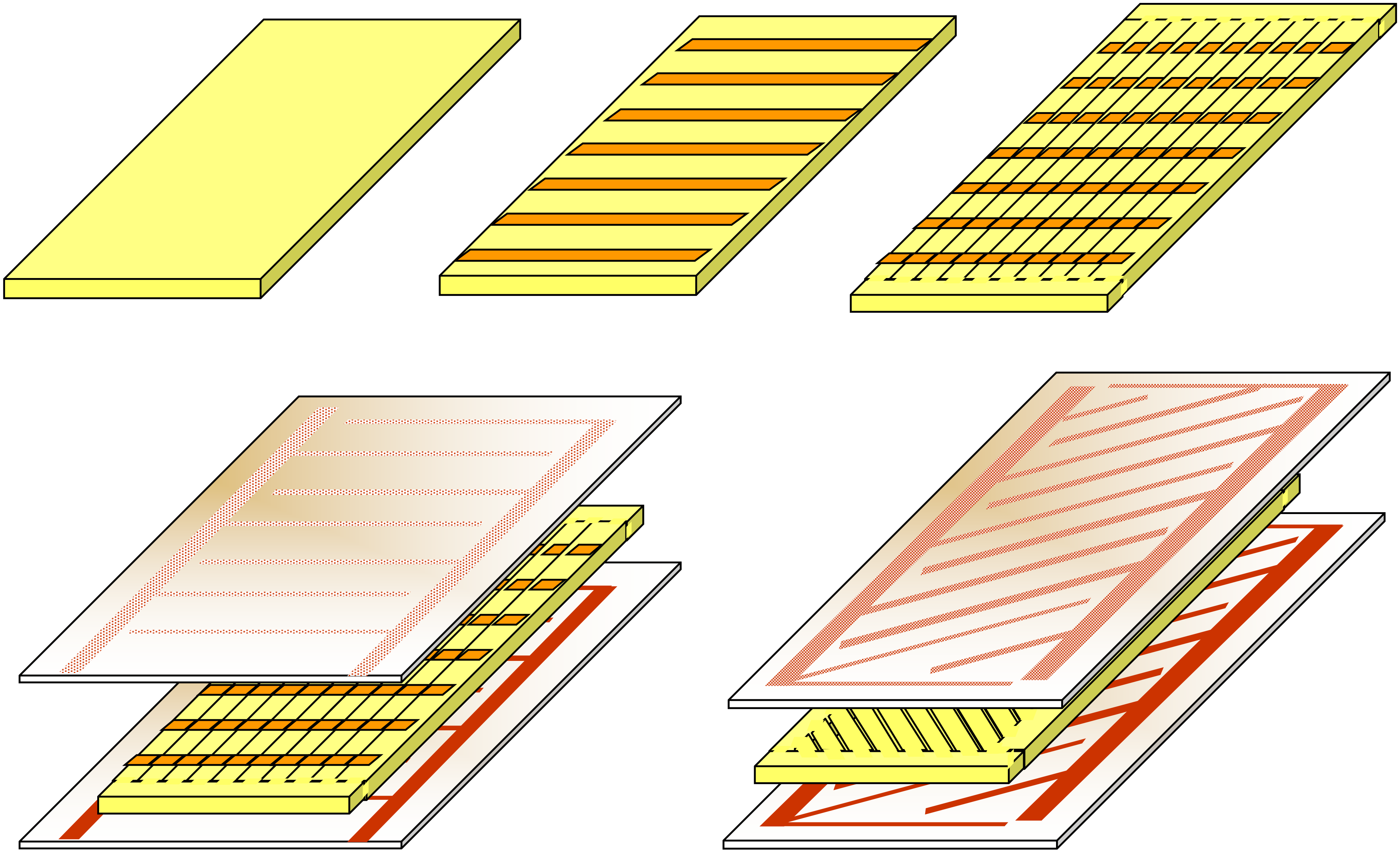
"LaRC AFC" Actuator: Initial Concept



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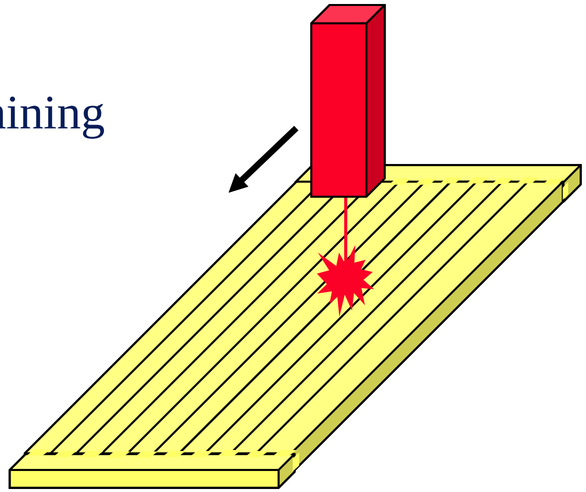
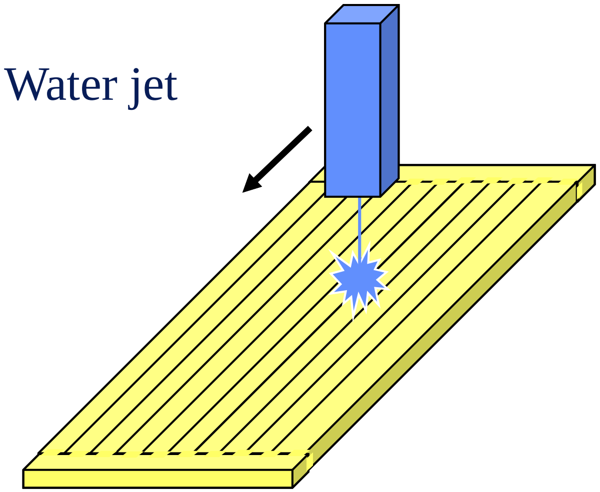
How to Make PZT Fiber Sheets?

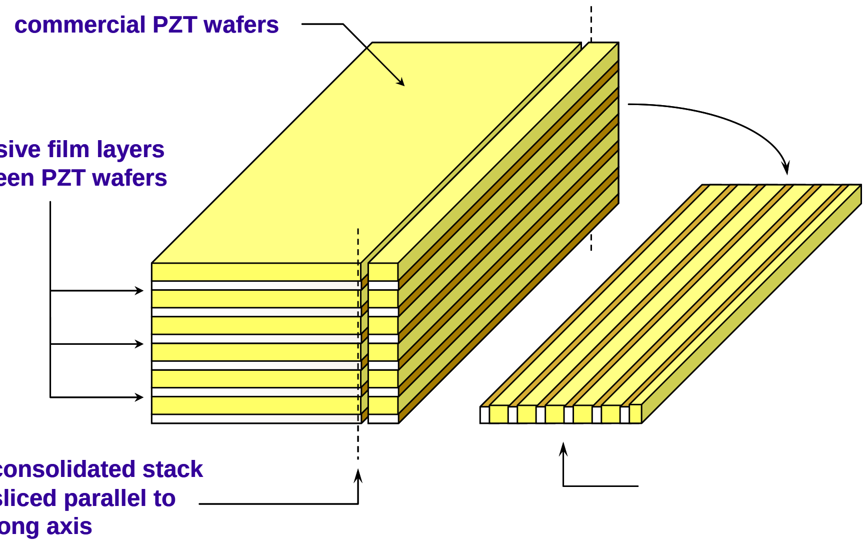
1. Laser machining



2. Water jet



3. Stack and slice



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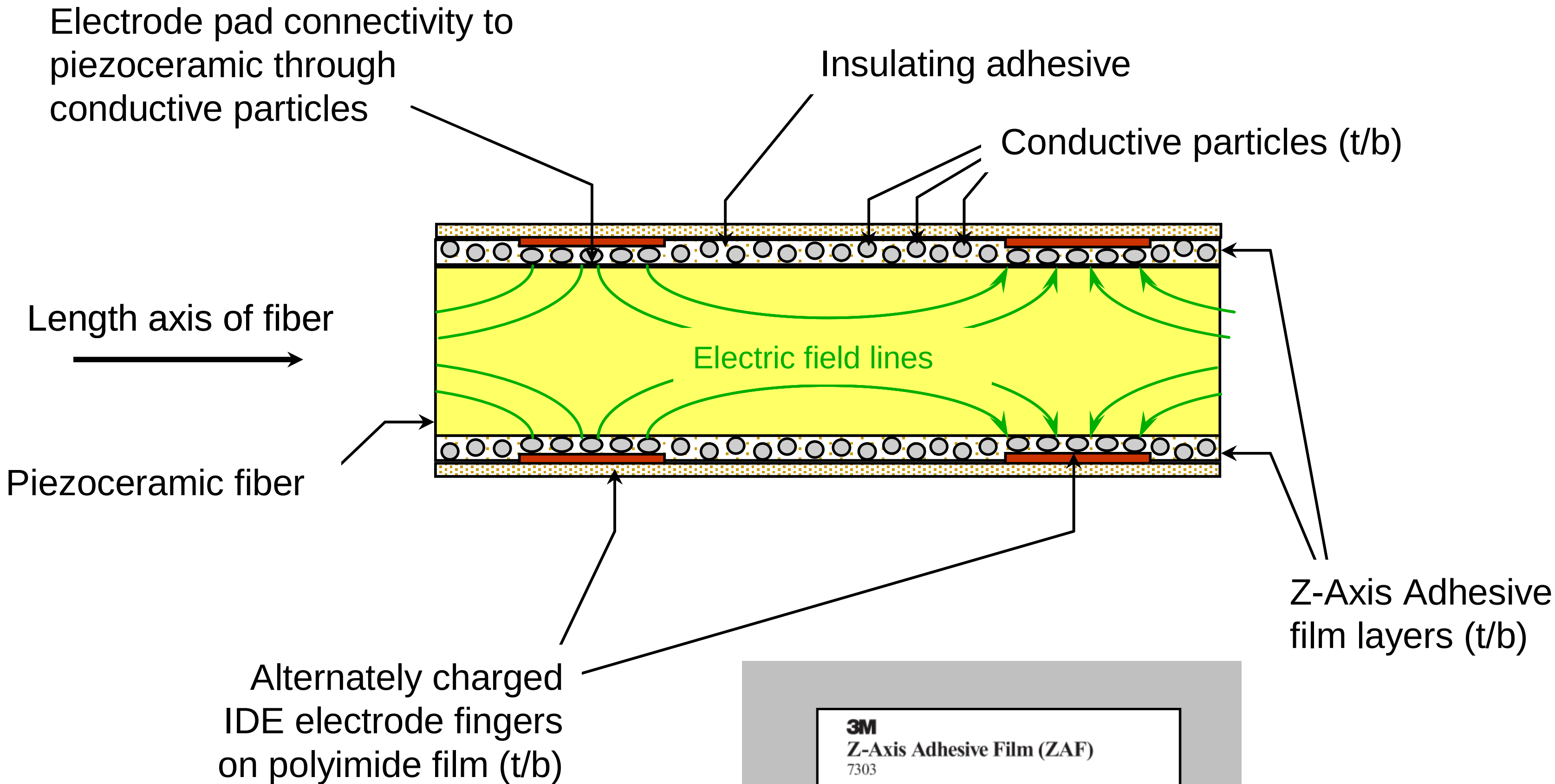
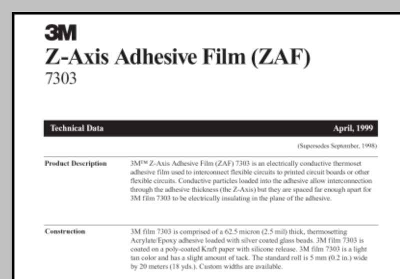
Electrode-Ceramic Interface Issues





3M

Z-Axis Adhesive Film (ZAF)
7303

Technical Data	April, 1999

(Supersedes September, 1998)

Product Description 3M™ Z-Axis Adhesive Film (ZAF) 7303 is an electrically conductive thermoset adhesive film used to interconnect flexible circuits to printed circuit boards or other flexible circuits. Conductive particles loaded into the adhesive allow interconnection through the adhesive thickness (the Z-Axis) but they are spaced far enough apart for 3M film 7303 to be electrically insulating in the plane of the adhesive.

Construction 3M film 7303 is comprised of a 62.5 micron (2.5 mil) thick, thermosetting Acrylate/Epoxy adhesive loaded with silver coated glass beads. 3M film 7303 is coated on a poly-coated Kraft paper with silicone release. 3M film 7303 is a light tan color and has a slight amount of tack. The standard roll is 5 mm (0.2 in.) wide by 20 meters (18 yds.). Custom widths are available.

Ref: http://www.3m.com

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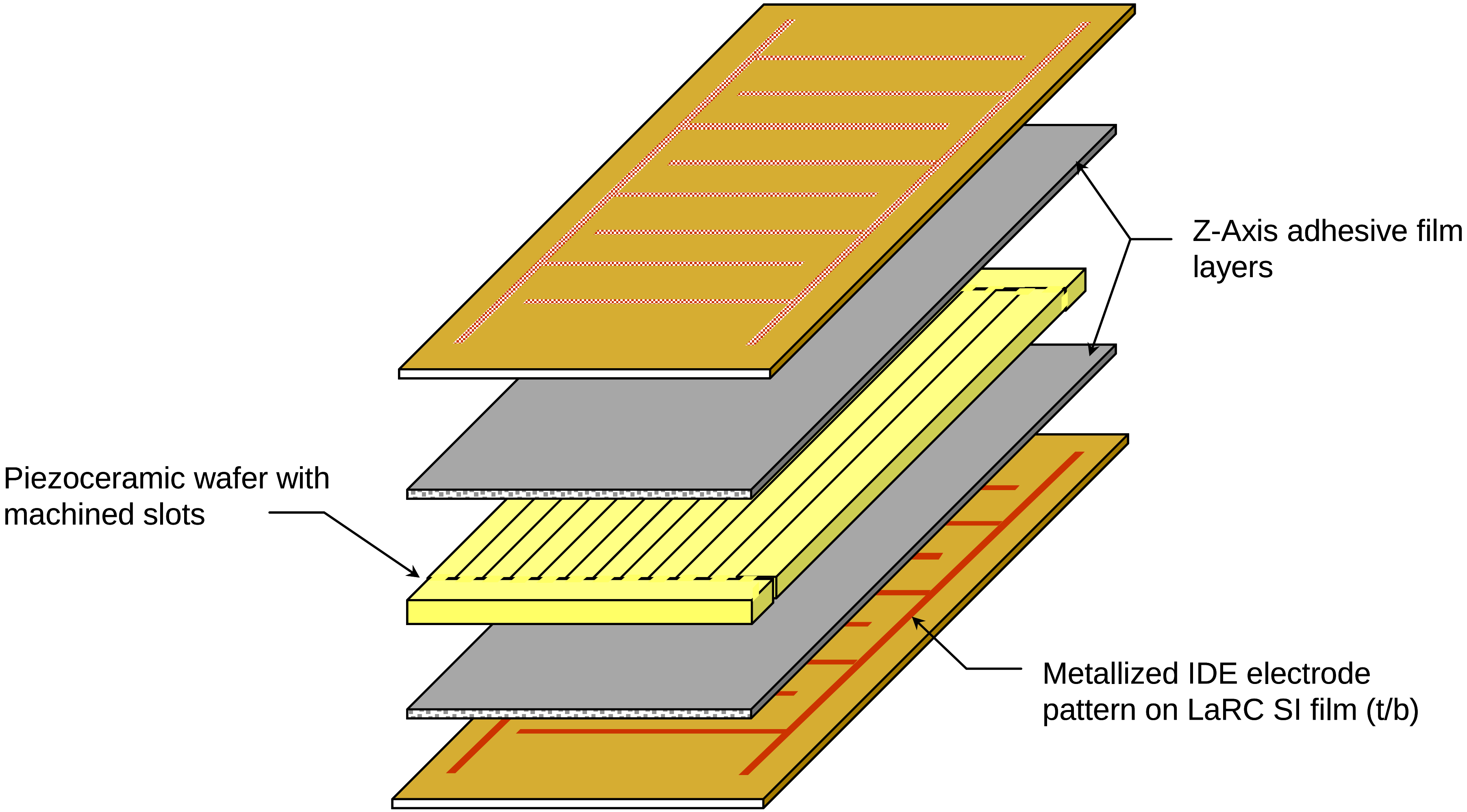
MFC: "Final" ZAF-based Working Concept



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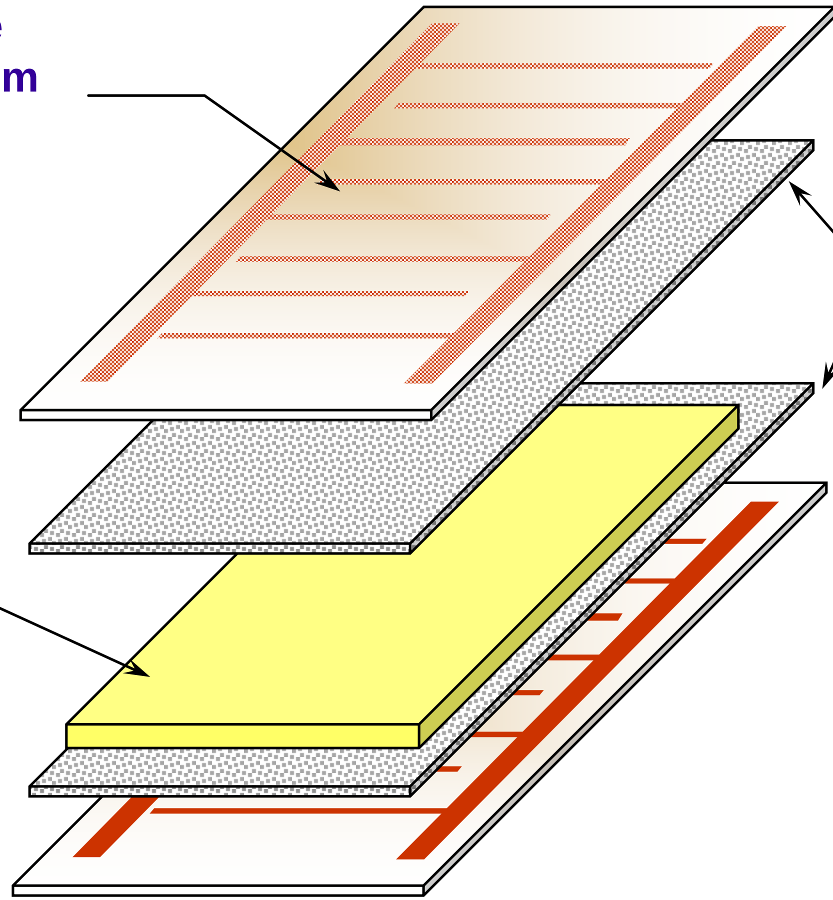
Monolithic PZT Reference Actuator

Interdigitated electrode pattern on polyimide film (t/b)

Permits in-plane poling and actuation of piezoceramic (d_{11} versus d_{31} advantage)



Electrode attachment with either:

(a) anisotropically conductive adhesive,

(b) structural epoxy with starved bond-line between electrodes and PZT

Reduces operating voltage by enabling direct electrical contact of electrodes and piezoceramic

Monolithic PZT wafer

Electrode rails not in direct contact with ceramic. (Eliminates cracking due to nonuniform field near rails.)

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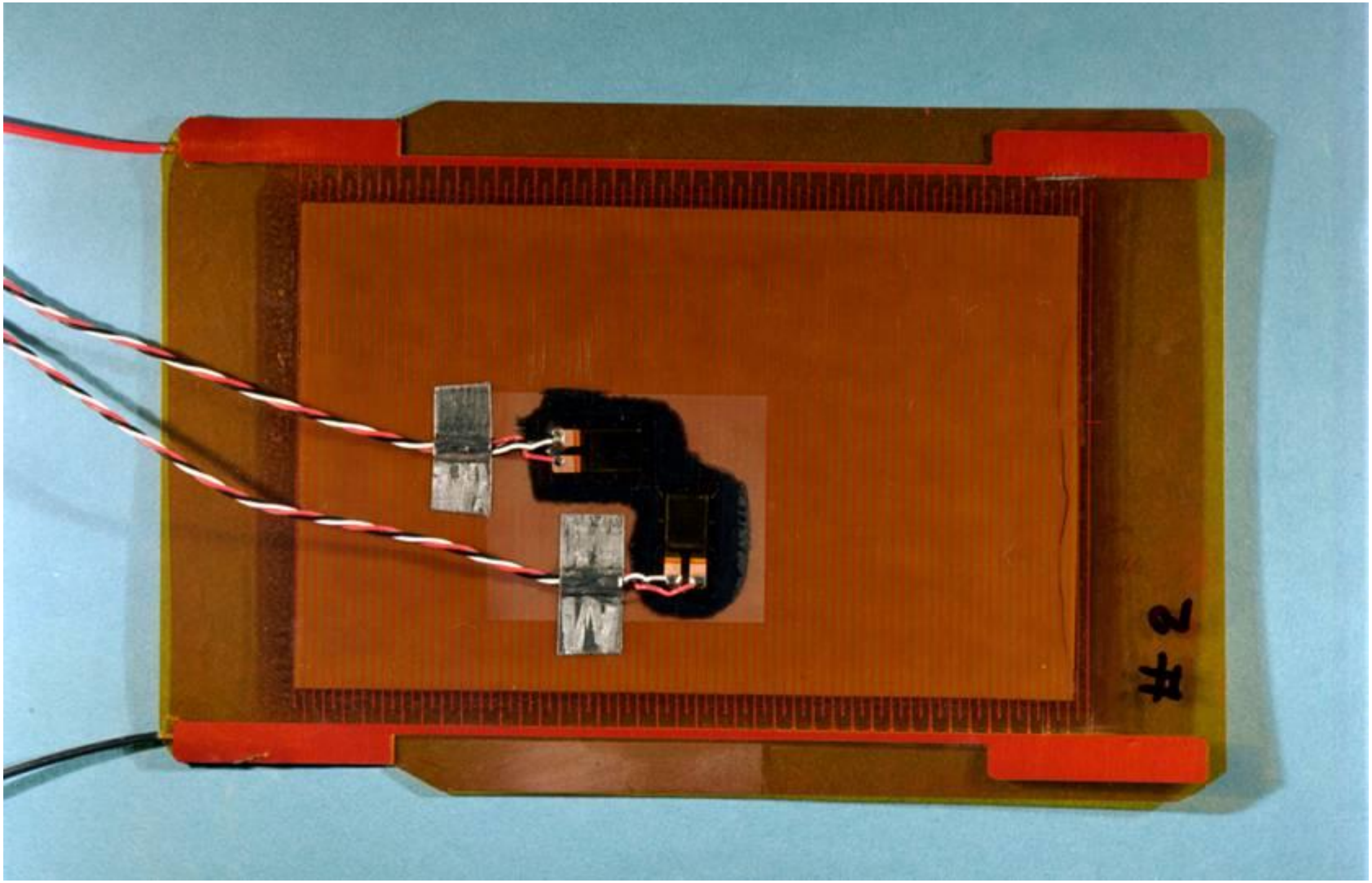
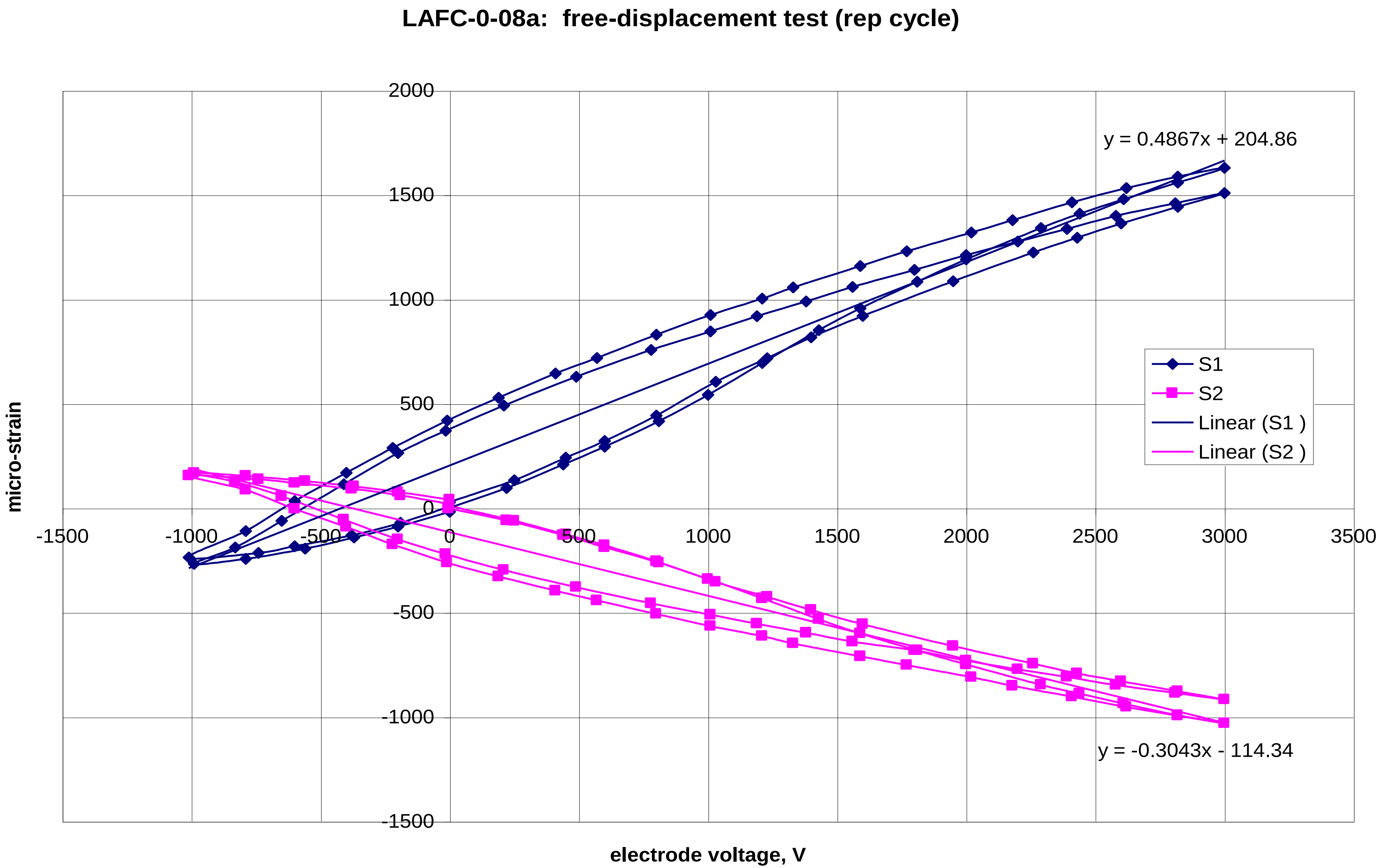
"MFC #2": ZAF Monolithic PZT Prototype



Wow! : Initial Monolithic Free-Strain Test Results



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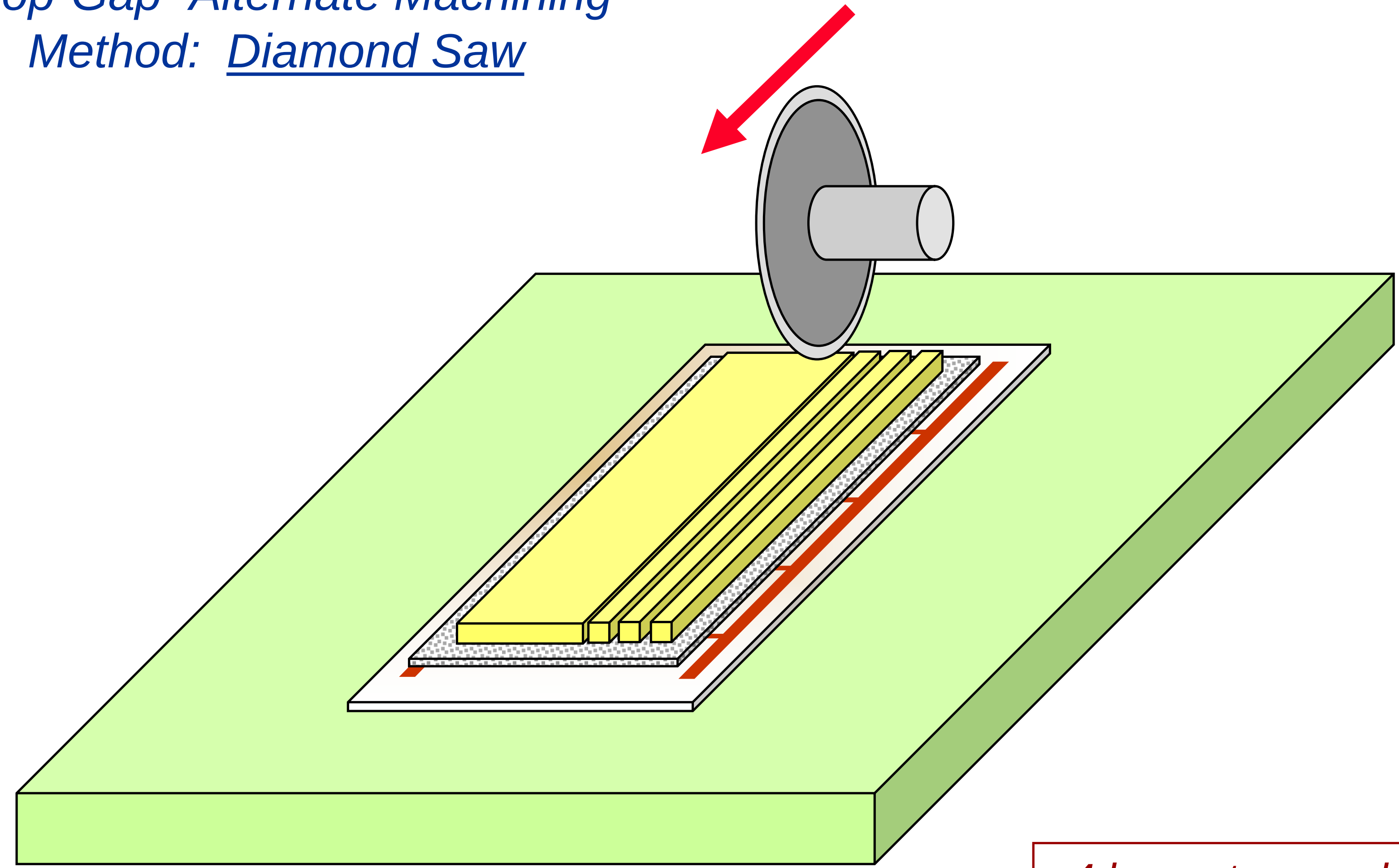
Problems With Fiber Machining …

"Stop-Gap" Alternate Machining Method: Diamond Saw



4 hours to complete one 3.375 x 2.25 in wafer!

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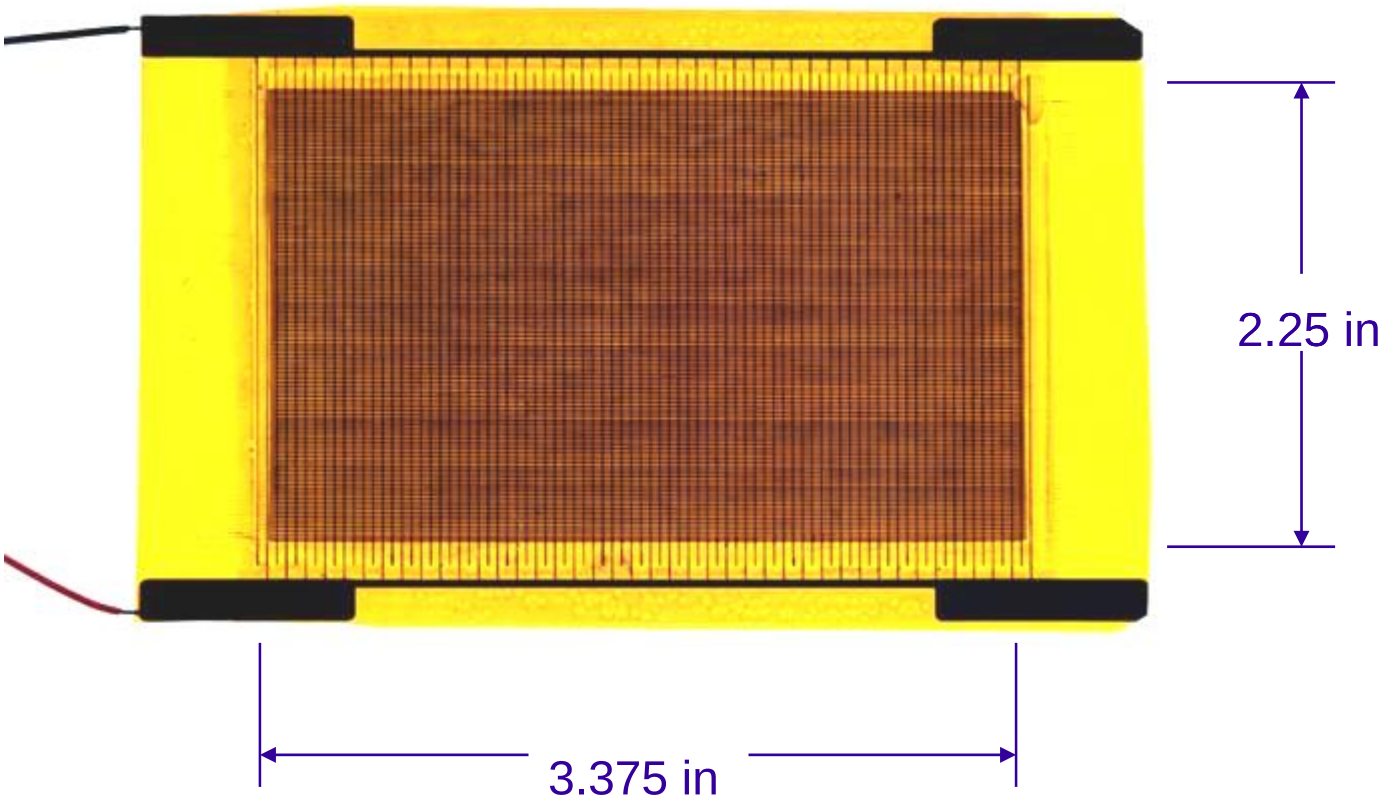
Machined PZT Fiber Prototype: Actuator thickness = 0.011



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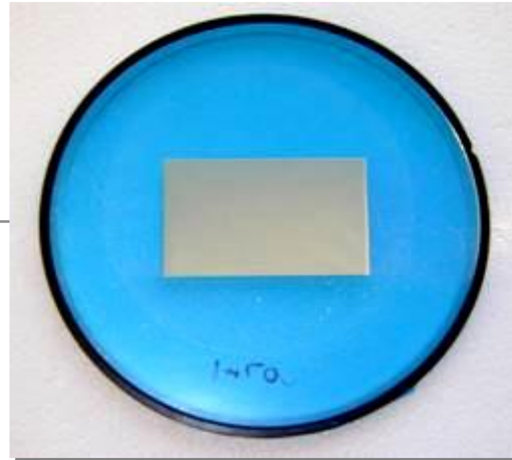
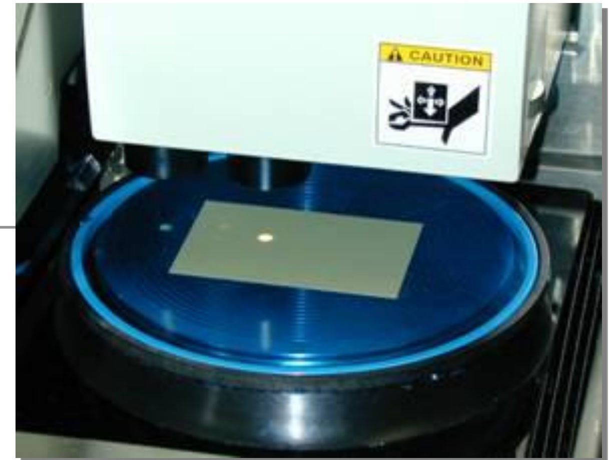
MFC: Final Fiber Sheet Manufacturing Process

Semiconductor wafer dicing saw



1. Ceramic wafer on grip-tape frame

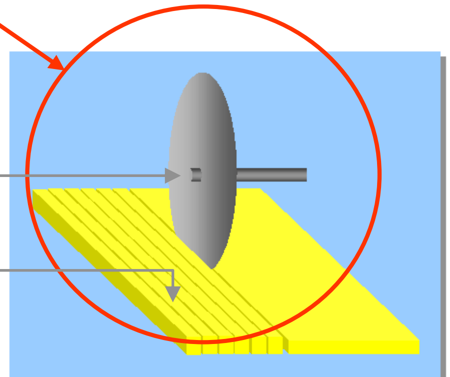


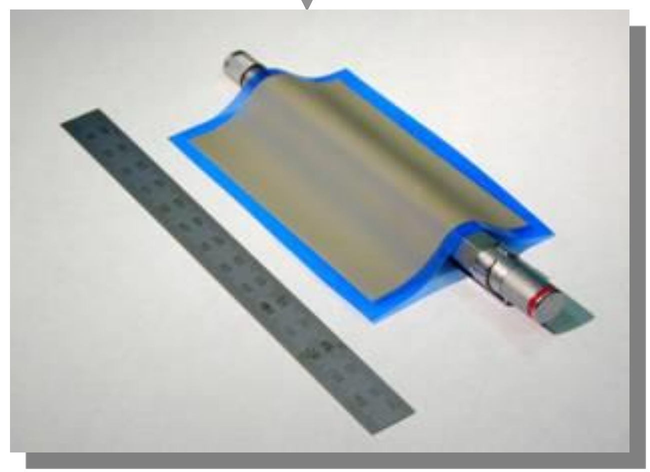
2. Wafer and grip-tape frame positioned for dicing

Diamond saw blade (1 - 3 mil thick)

Piezoceramic wafer (5 - 9 mil thick)

Polymer grip film (5 mil thick)





3. Completed piezoceramic fiber sheet

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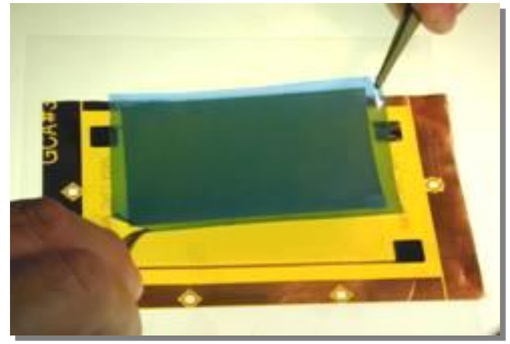
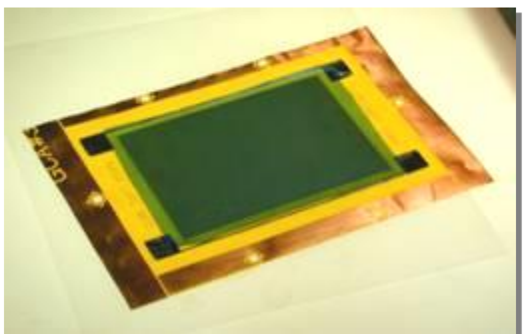
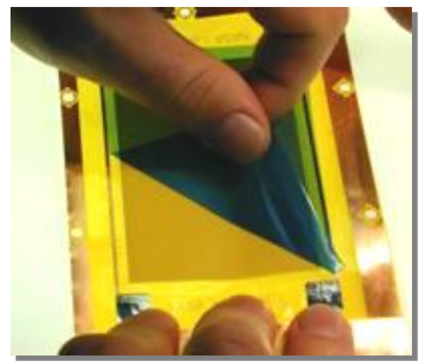
a) Preparation of bottom electrode film with epoxy adhesive.



b) Placement of fiber sheet on electrode film.



c) Fiber sheet and electrode film after heat tacking.



d) Removal of polymer carrier film from transferred piezoceramic fibers.

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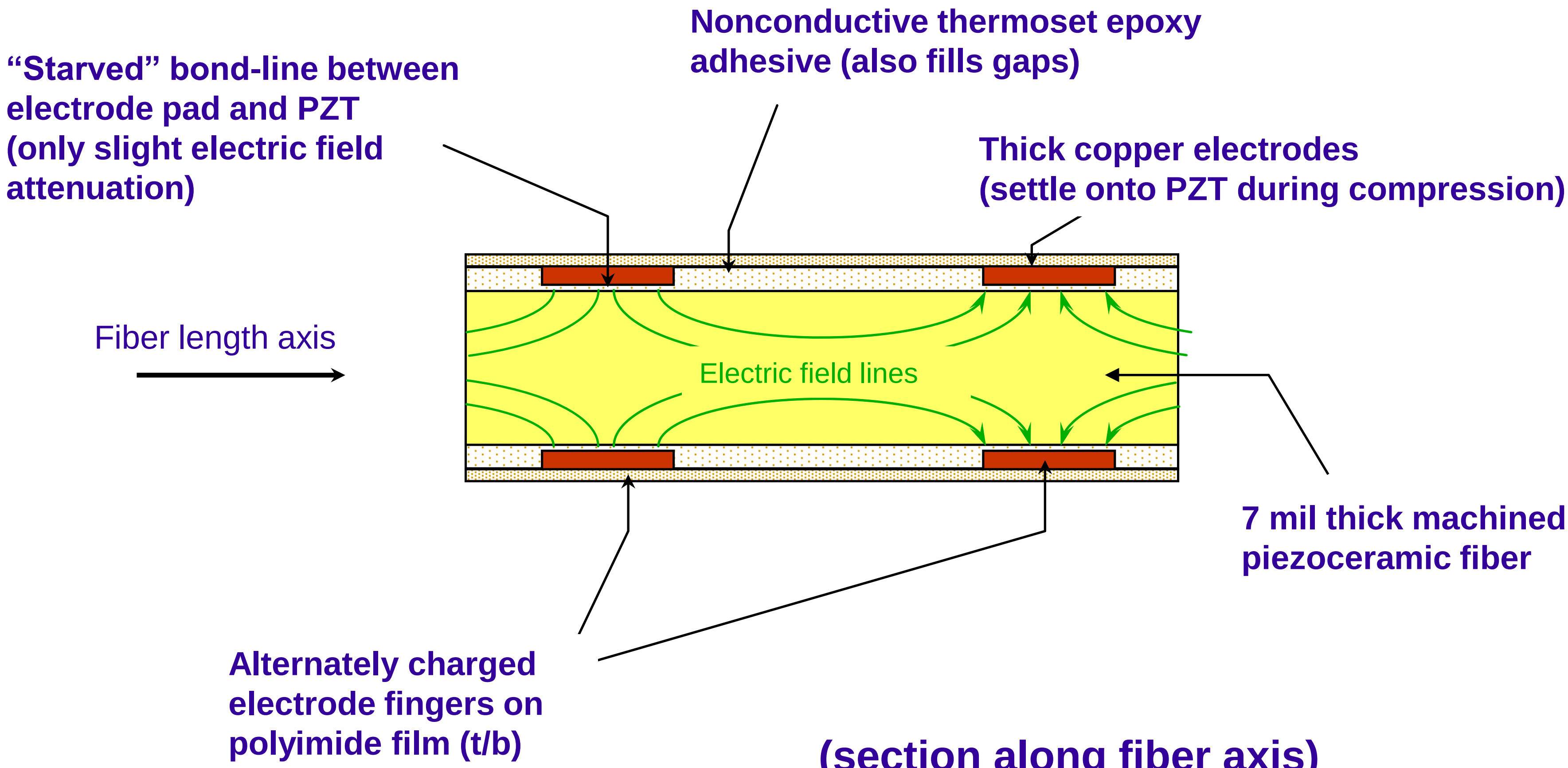
ZAF or No ZAF?



(section along fiber axis)

Epoxy-Only Electrode Attachment ("ZAF-less "MFC")

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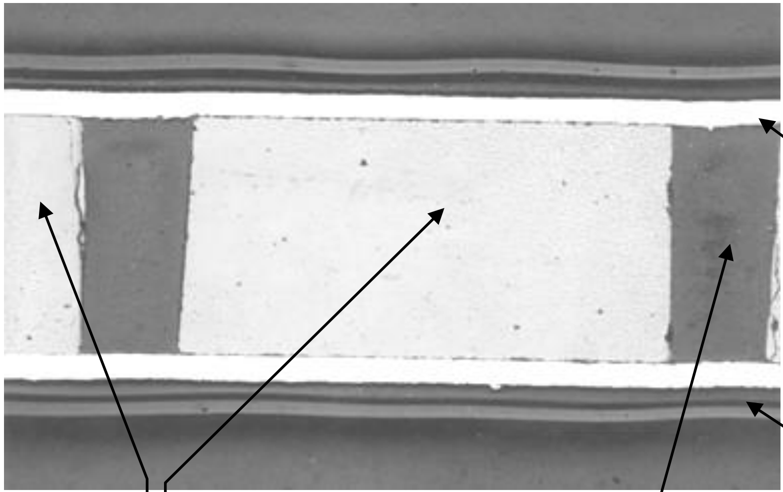
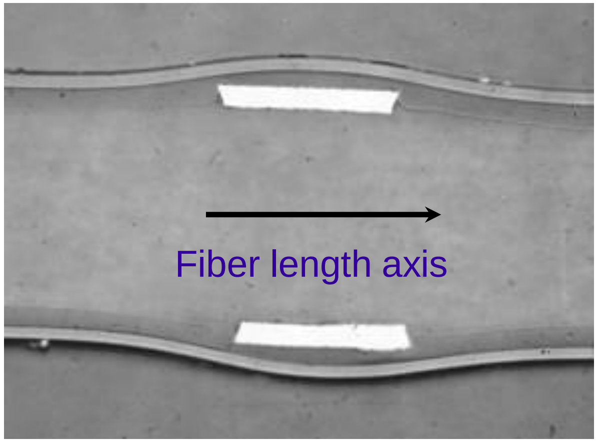


(A-A) Microphotograph across fiber axis.



(B-B) Microphotograph along fiber axis.

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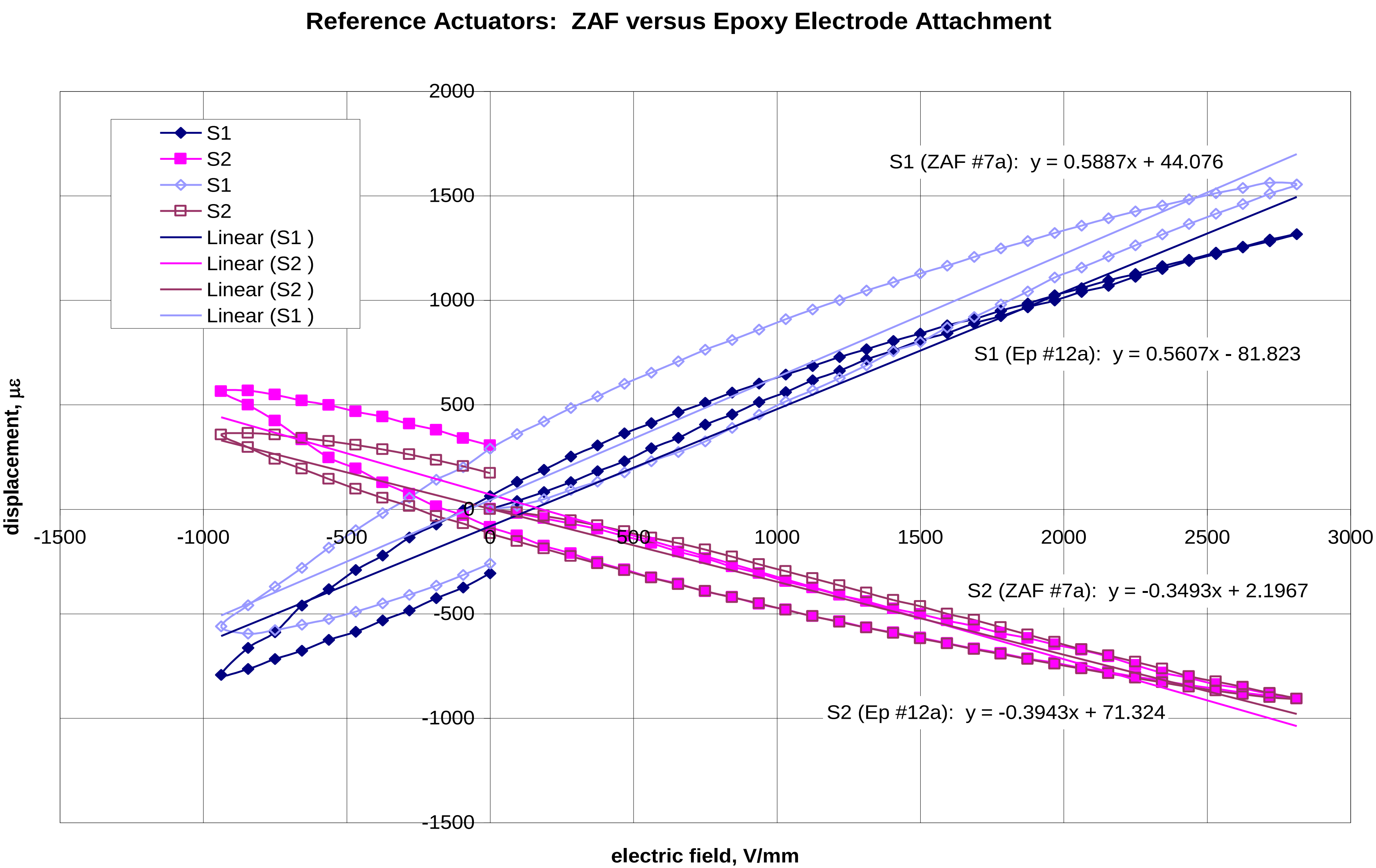
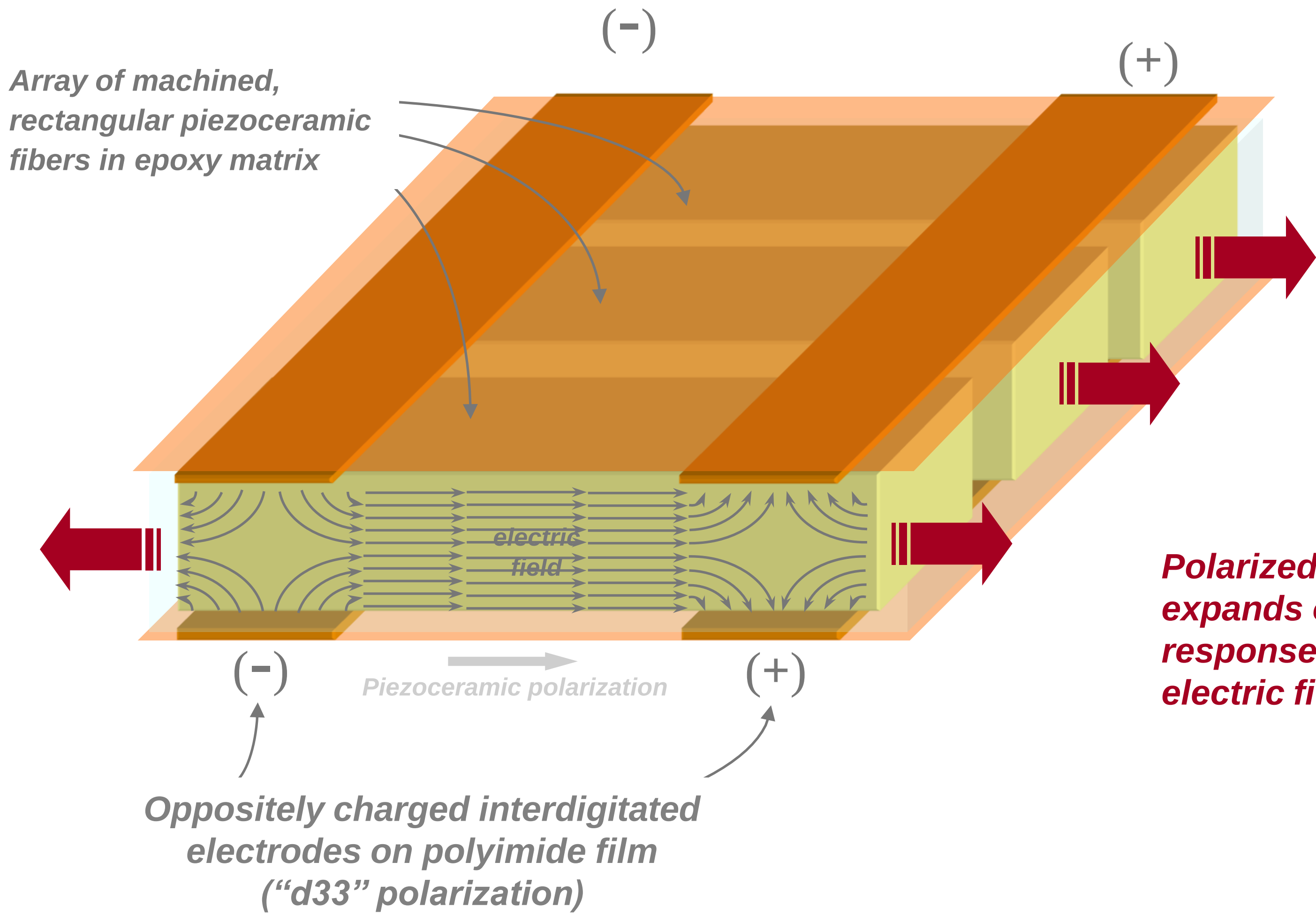
ZAF vs. Epoxy Testing



MFC: "Final" Design (ca. October 1998)



Polarized piezoceramic expands or contracts in response to applied electric field

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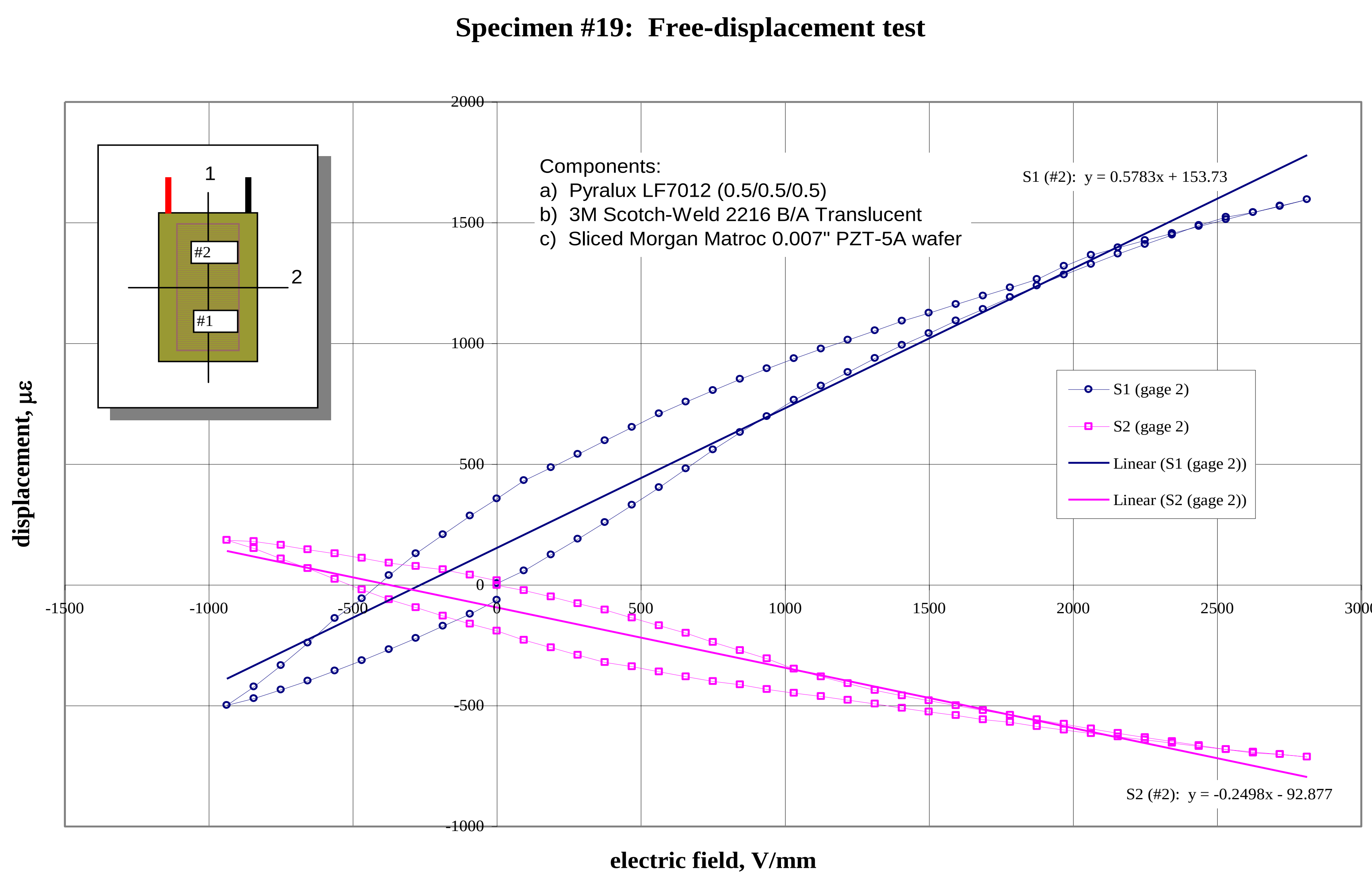
MFC: "Final" Design Free-strain Performance



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MFC Fabrication Process Documentation

NASA/ TM-2003-212427
ARL-TR-2833

Method for Fabricating NASA-Standard Macro-Fiber Composite Piezoelectric Actuators

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Langley Research Center, Hampton, Virginia

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U.S. Army Research Laboratory
Vehicle Technology Directorate
Langley Research Center, Hampton, Virginia

June, 2003

US006629341B2

(12) United States Patent
Wilkie et al.

(10) Patent No.: US 6,629,341 B2
(45) Date of Patent: Oct. 7, 2003

(54) **METHOD OF FABRICATING A PIEZOELECTRIC COMPOSITE APPARATUS**

(75) Inventors: **W. Keats Wilkie**, Williamsburg, VA (US); **Robert G. Bryant**, Newport News, VA (US); **Robert L. Fox**, Hayes, VA (US); **Richard F. Hellbaum**, Hampton, VA (US); **James W. High**, Norfolk, VA (US); **Antony Jalink, Jr.**, Newport News, VA (US); **Bruce D. Little**, Gloucester, VA (US); **Paul H. Mirick**, Grafton, VA (US)

(73) Assignee: **The United States of America as represented by the Administrator of the National Aeronautics and Space Administration**, Washington, DC (US)

(21) Appl. No.: **09/430,677**

(22) Filed: **Oct. 29, 1999**

(56) **References Cited**

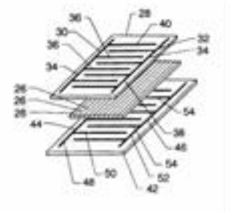
U.S. PATENT DOCUMENTS

OTHER PUBLICATIONS

(57) **ABSTRACT**

A method for fabricating a piezoelectric macro-fiber composite actuator comprises providing a piezoelectric material that has two sides and attaching one side upon an adhesive backing sheet. The method further comprises slicing the piezoelectric material to provide a plurality of piezoelectric fibers in juxtaposition. A conductive film is then adhesively bonded to the other side of the piezoelectric material, and the adhesive backing sheet is removed. The conductive film has first and second conductive patterns formed thereon which are electrically isolated from one another and in electrical contact with the piezoelectric material. The first and second conductive patterns of the conductive film each have a plurality of electrodes to form a pattern of interdigitated electrodes. A second film is then bonded to the other side of the piezoelectric material. The second film may have a pair of conductive patterns similar to the conductive patterns of the first film.

15 Claims, 6 Drawing Sheets



LaRC-MFC: 2000 R&D100 Award Winners

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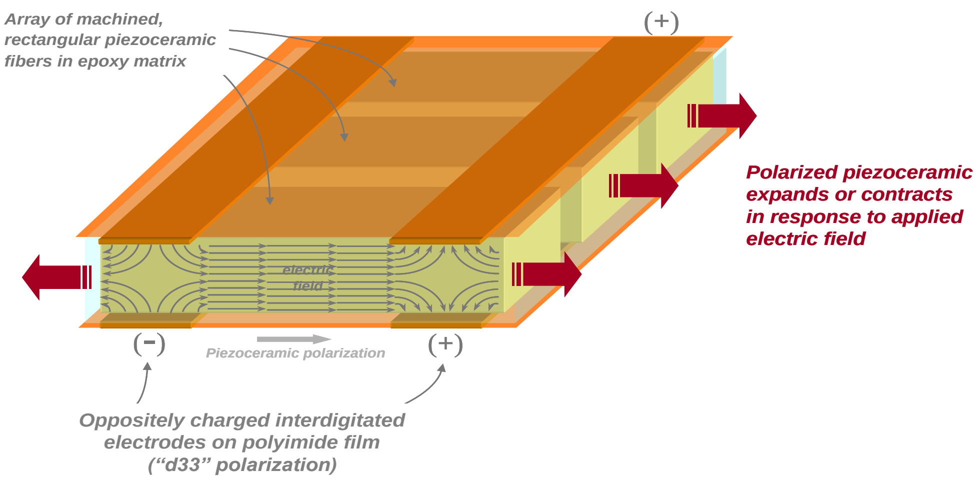
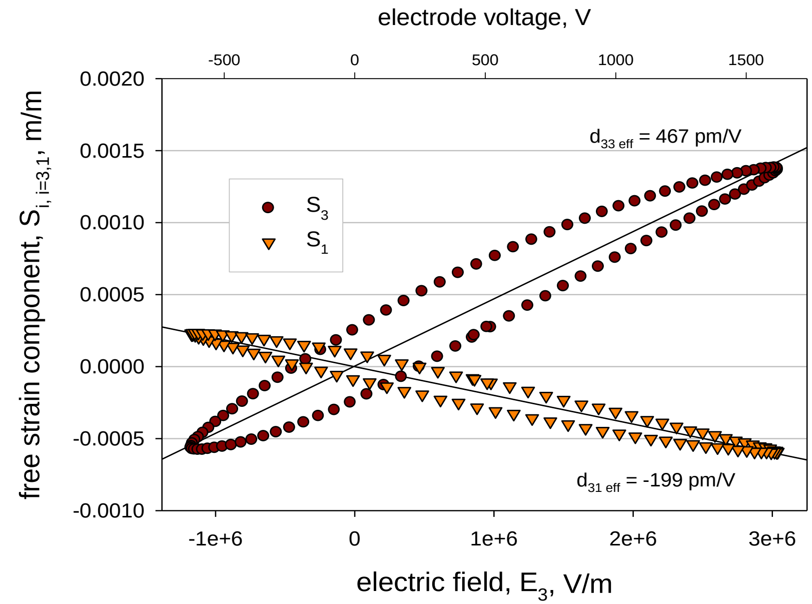
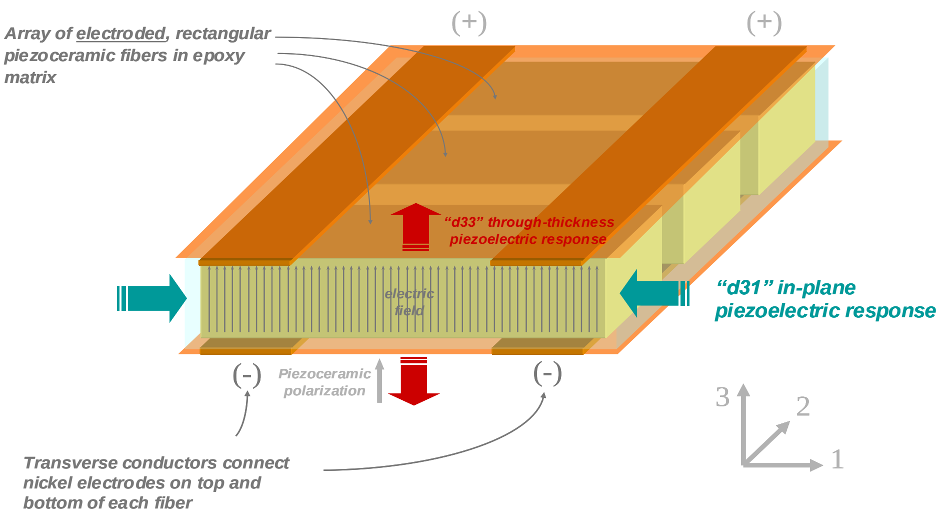
MFC: Current Architectures (ca. 2005)

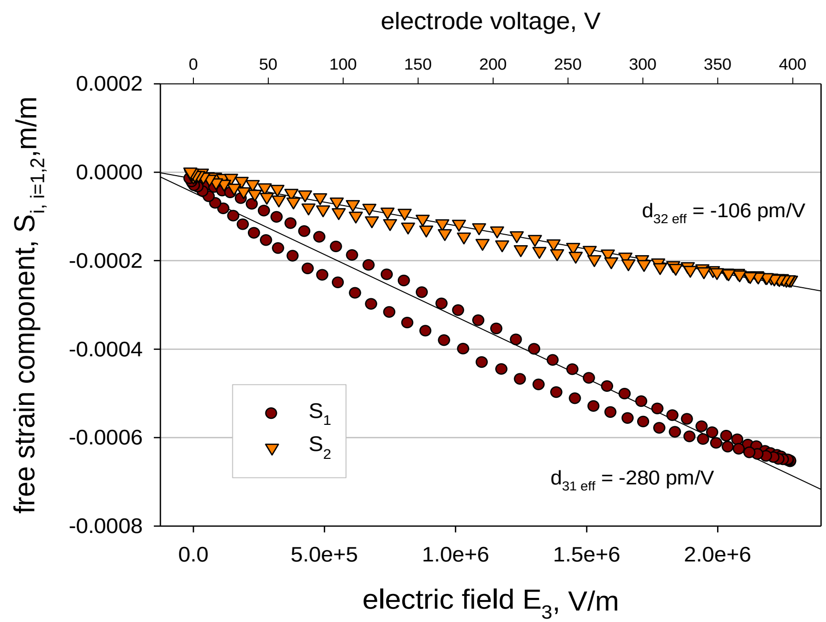
Standard "d_{33}" polarization





Alternate "d_{31}" polarization





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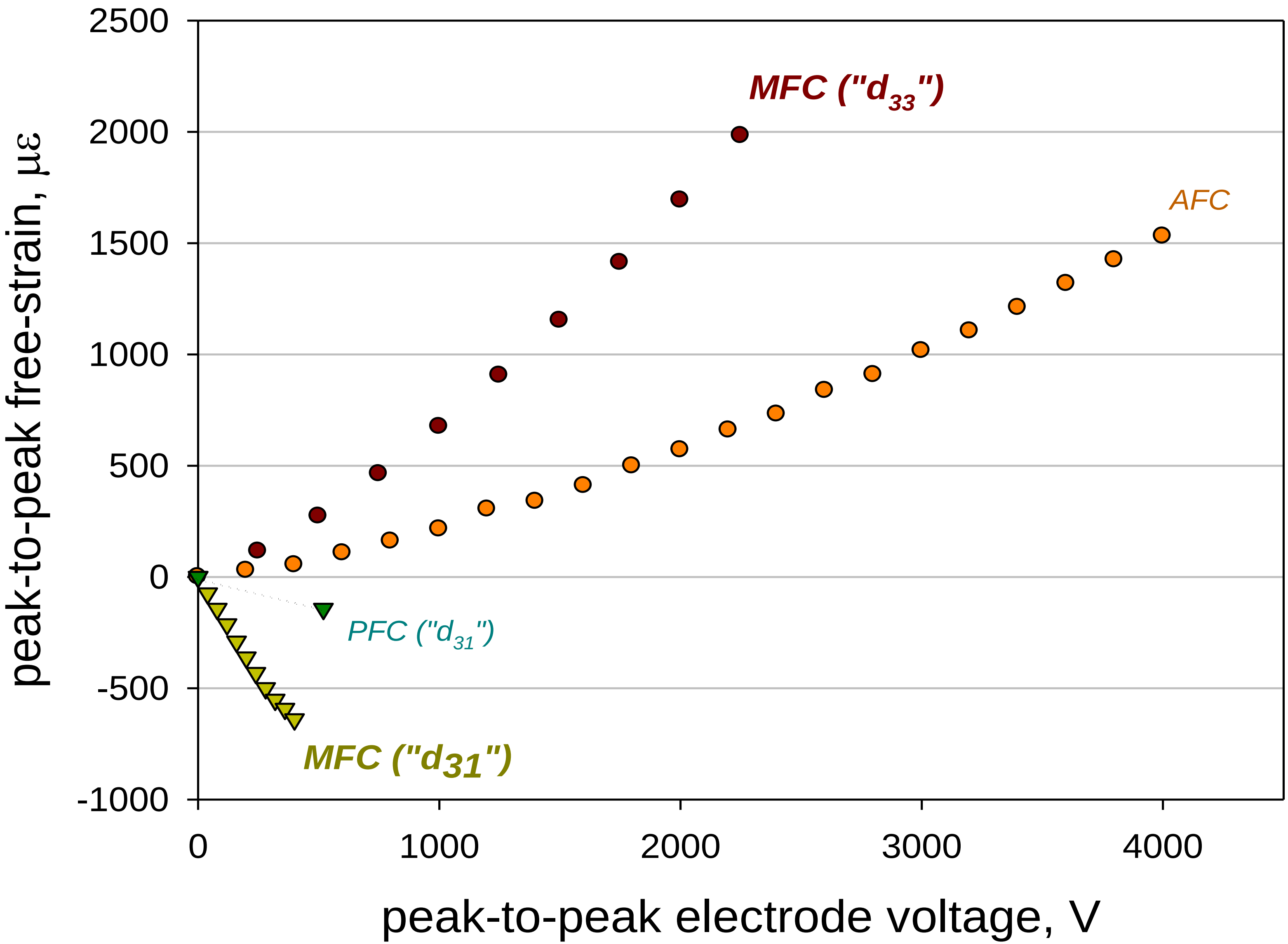
Piezocomposite Free Strain Performance Comparison



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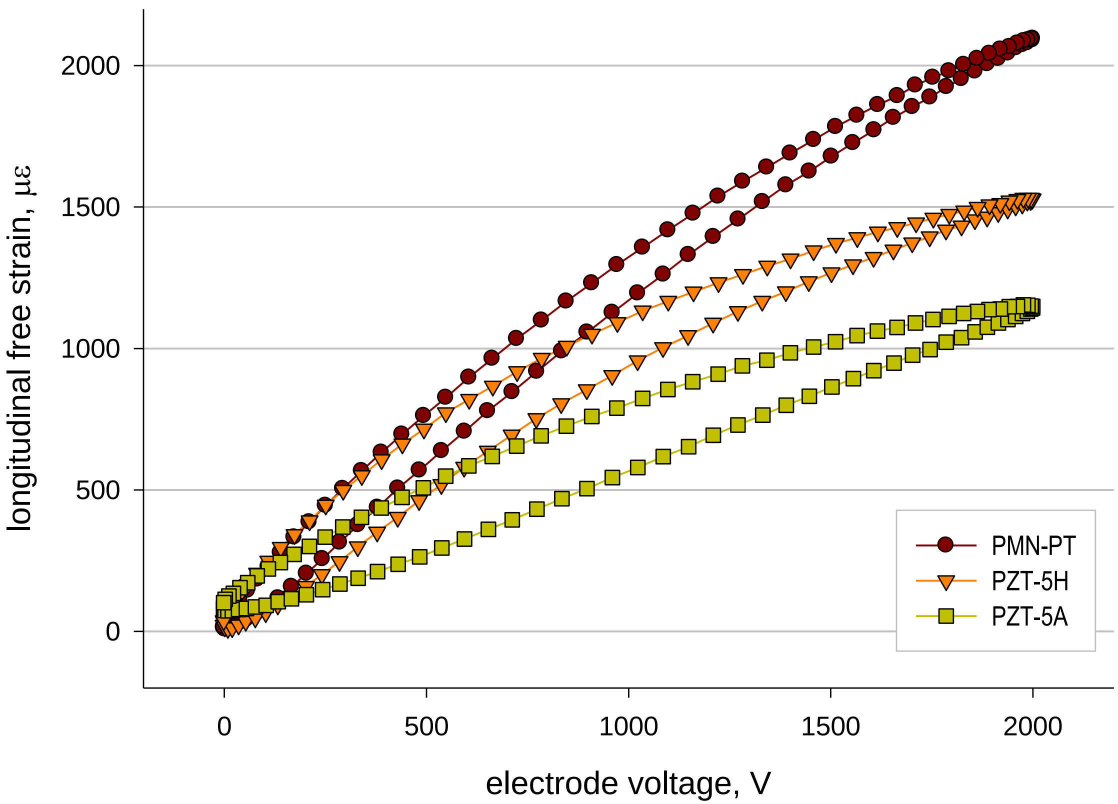
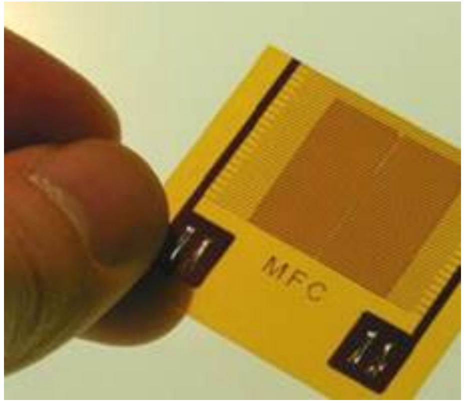
Single-Crystal MFC: High-Field Strain Comparison

Unipolar Drive Results



20 mm MFC Test Specimens



material	$S_3/S_{3,PZT-5A}$ †	$\bar{d}_{33}/\bar{d}_{33,PZT-5A}$	*Δ%* $_{3\text{-}dir}$ ‡
PZT-5A	1.0	1.0	-
PZT-5H	1.40	1.66	+18.6%
PMN-PT	1.96	4.88	+149%

$$\bar{d}_{33} = \frac{d_{33,f}}{\left(1+\frac{\phi_m}{\phi_f}\frac{s^E_{33,f}}{s^E_{33,m}}\right)}$$

material	K_3^T *(1kHz)*	k_{33}	d_{33}*, pm/V*	d_{31}*, pm/V*	ρ*, g/cm*^{3}	s_{33}^{E} †	s_{11}^E	s_{13}^E	s_{44}^E
PZT-5A	1900	0.72	390	-190	7.8	18.8	16.4	-7.22	47.5
PZT-5H	3800	0.75	650	-320	7.8	20.7	16.5	-9.1	43.5
PMN-PT	7151	0.91	2285	-1063	8.05	86.5	59.7	-45.3	14.4

† elastic constants, s, 10^{-12} m^2/N

Refs.: Jaffe, Cook, Jaffe; CTS Wireless; Morgan-Matroc, TRS

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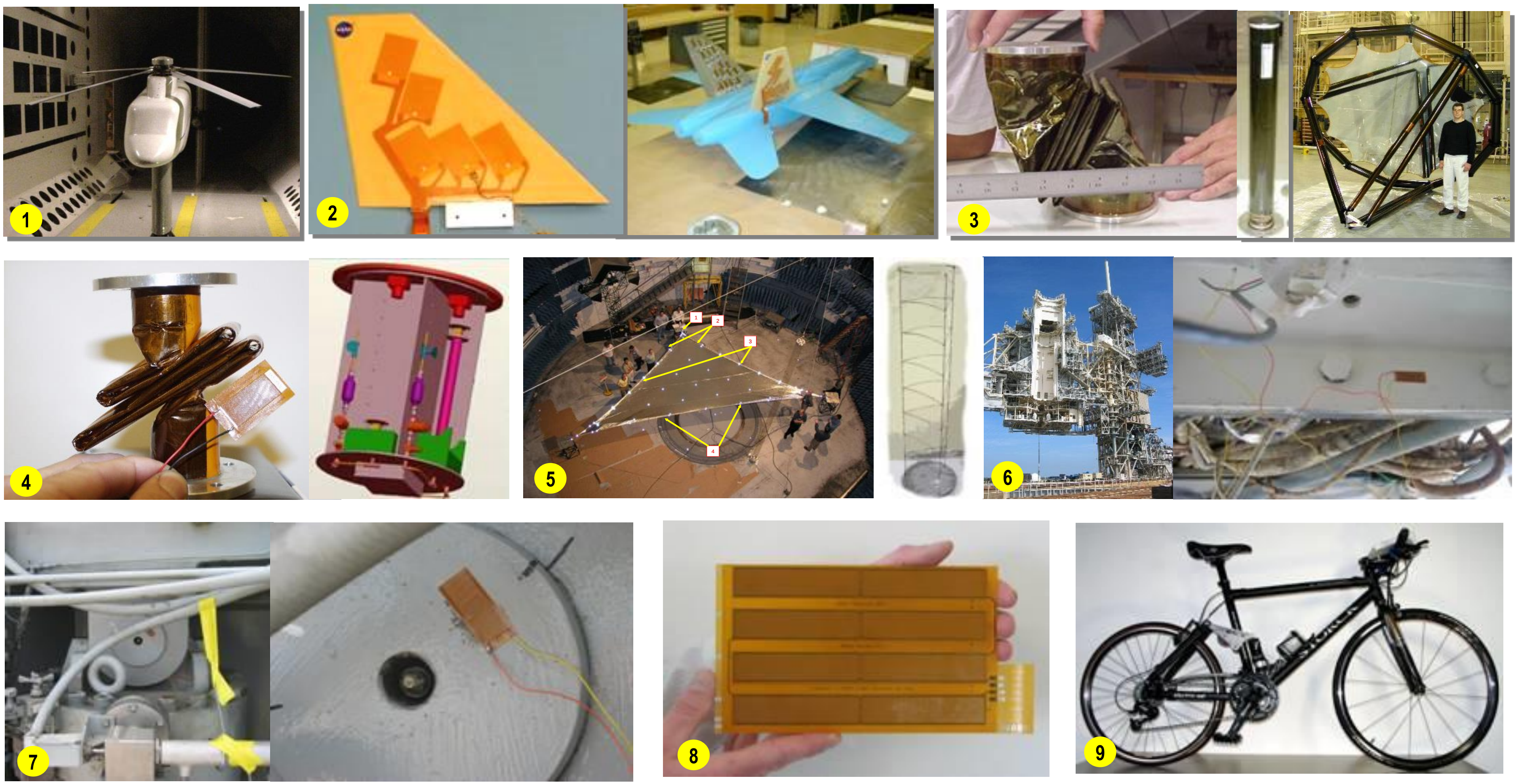
Selected MFC Sensor and Actuator Applications



1 Active Twist Rotor (NASA, ARL, University of Michigan, Sikorsky), 2 Twin-tail buffet loads alleviation (NASA, AFRL, Boeing), 3
Active inflatable-rigidizeable spacecraft structures (NASA, JPL, DoD, L'GARDE, ILC Dover), 4 On-orbit rigidizeable structures
dynamics Shuttle flight experiment (AFIT), 5 Solar-sail structures on-orbit dynamics system identification (NASA, AEC Able), 6
KSC launch tower white room impedance-based health monitoring (Virginia Tech, LANL), 7 KSC crawler bearing health monitoring
(Virginia Tech, LANL), 8 Automotive drive shaft active vibration damping (Volkswagen R&D, Smart Material Corp.), and 9
Structural loads sensing and energy harvesting (University of Munich, Storck Bicycle, Smart Material Corp.)

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Billy Derbes
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