



NASA MFC Piezocomposites: A Development History

W. Keats Wilkie

Senior Member Technical Staff

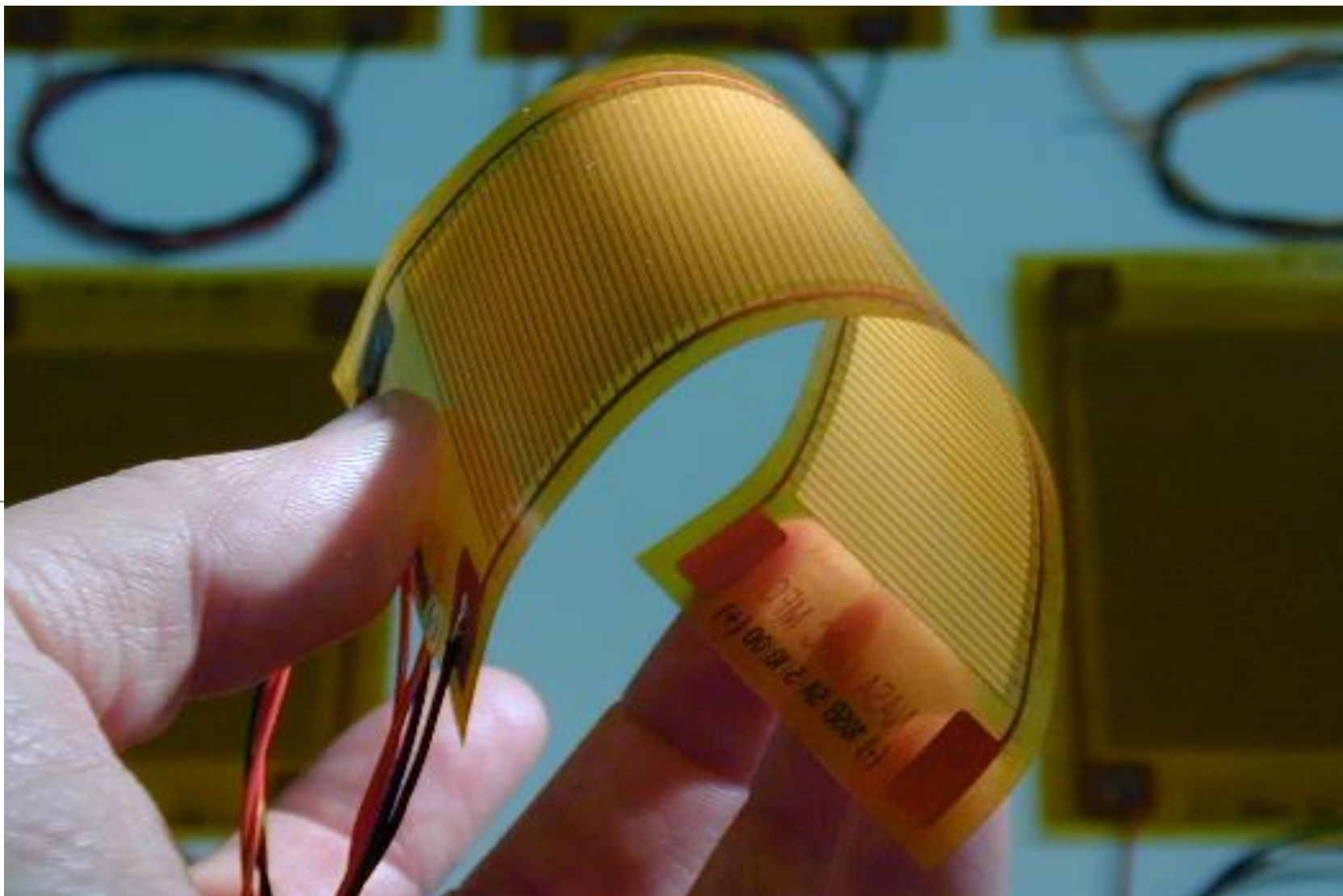
Mechanical Systems Engineering Research Division

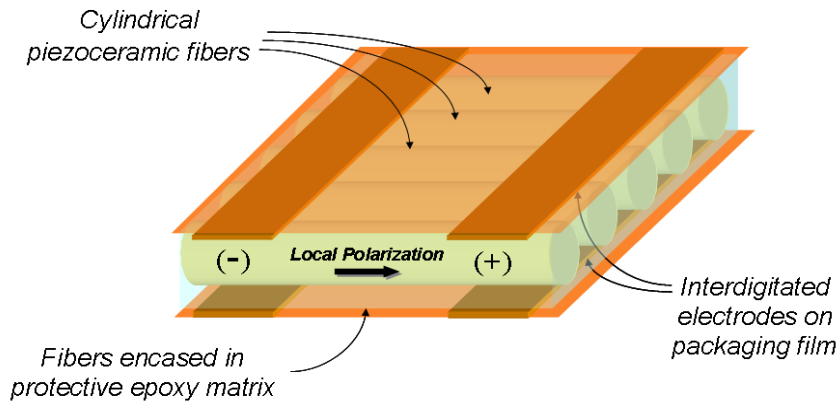
NASA Jet Propulsion Laboratory

California Institute of Technology

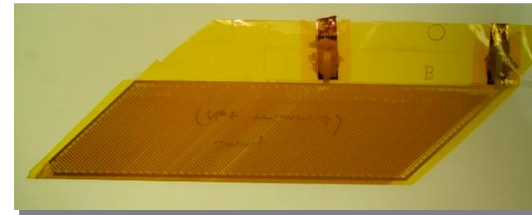


NASA Macro-Fiber Composite Actuator (MFC)

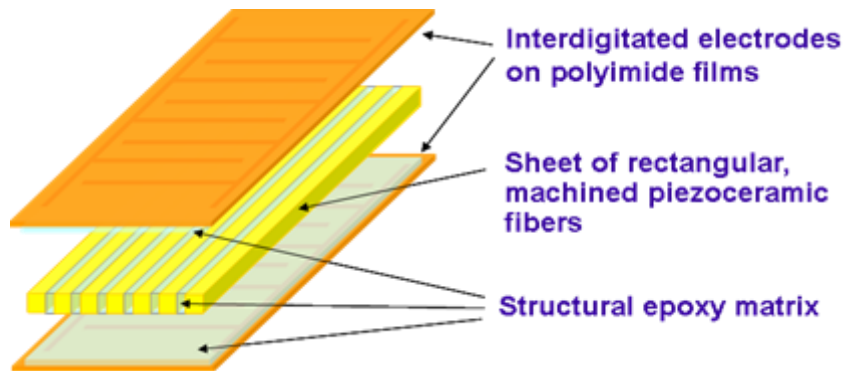
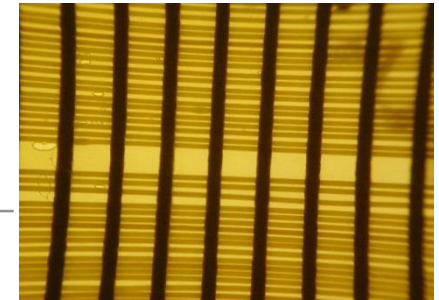




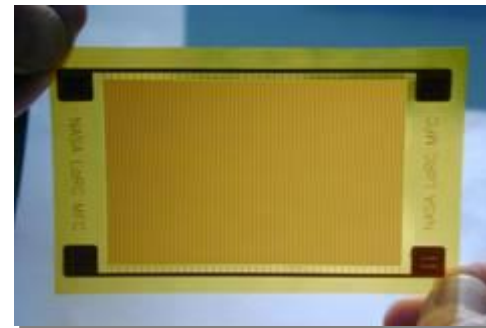
1st generation device: AFC (MIT, 1993-2000)



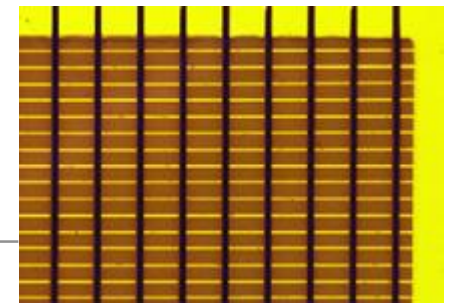
irregular construction



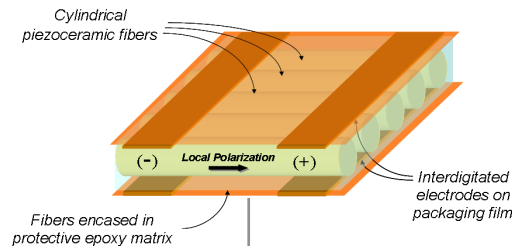
Advanced piezocomposite: MFC (NASA, ARL, 1997-2003)



precision construction



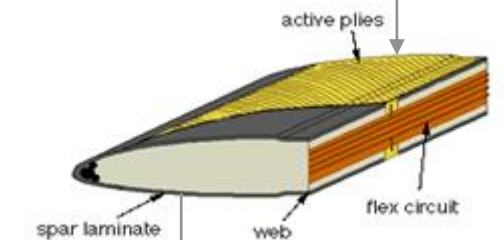
1. Piezoelectric Composite Actuator



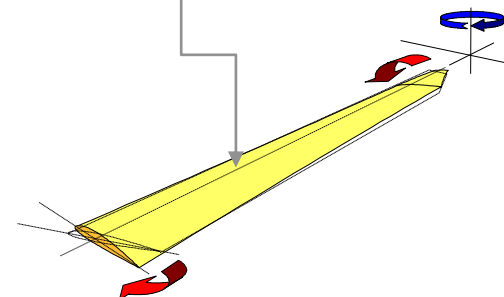
2. Active Fiber Composite Plies



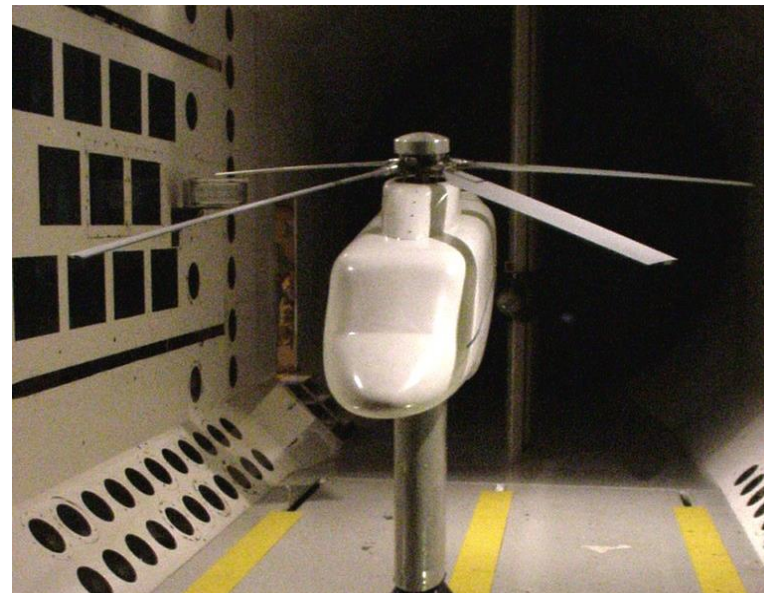
3. Active Composite Structure



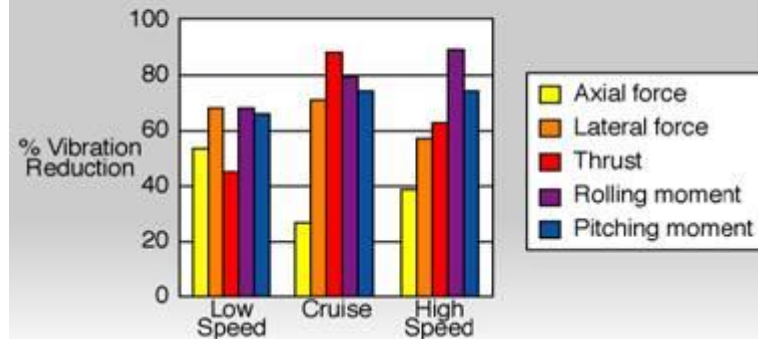
4. Active Twist Control



4. Active Twist Rotor In Wind Tunnel

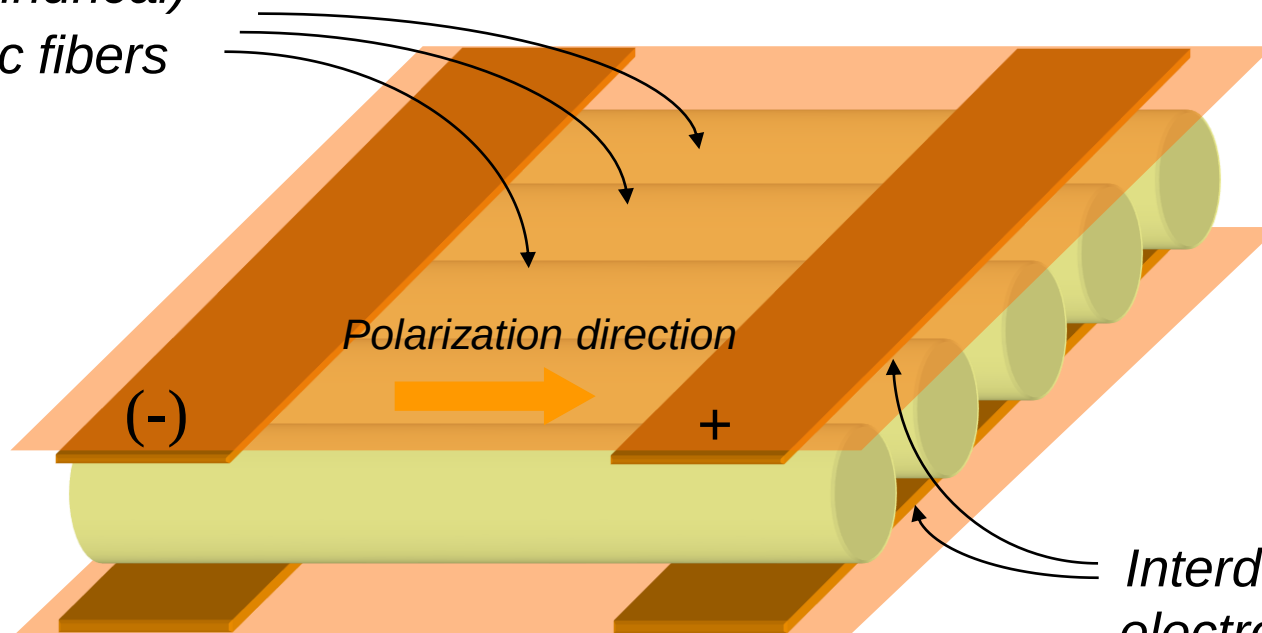


Measured Closed-Loop Vibration reduction of fixed-System Loads



(MIT, 1995)

*Extruded (cylindrical)
piezoceramic fibers*



Polarization direction

(-)

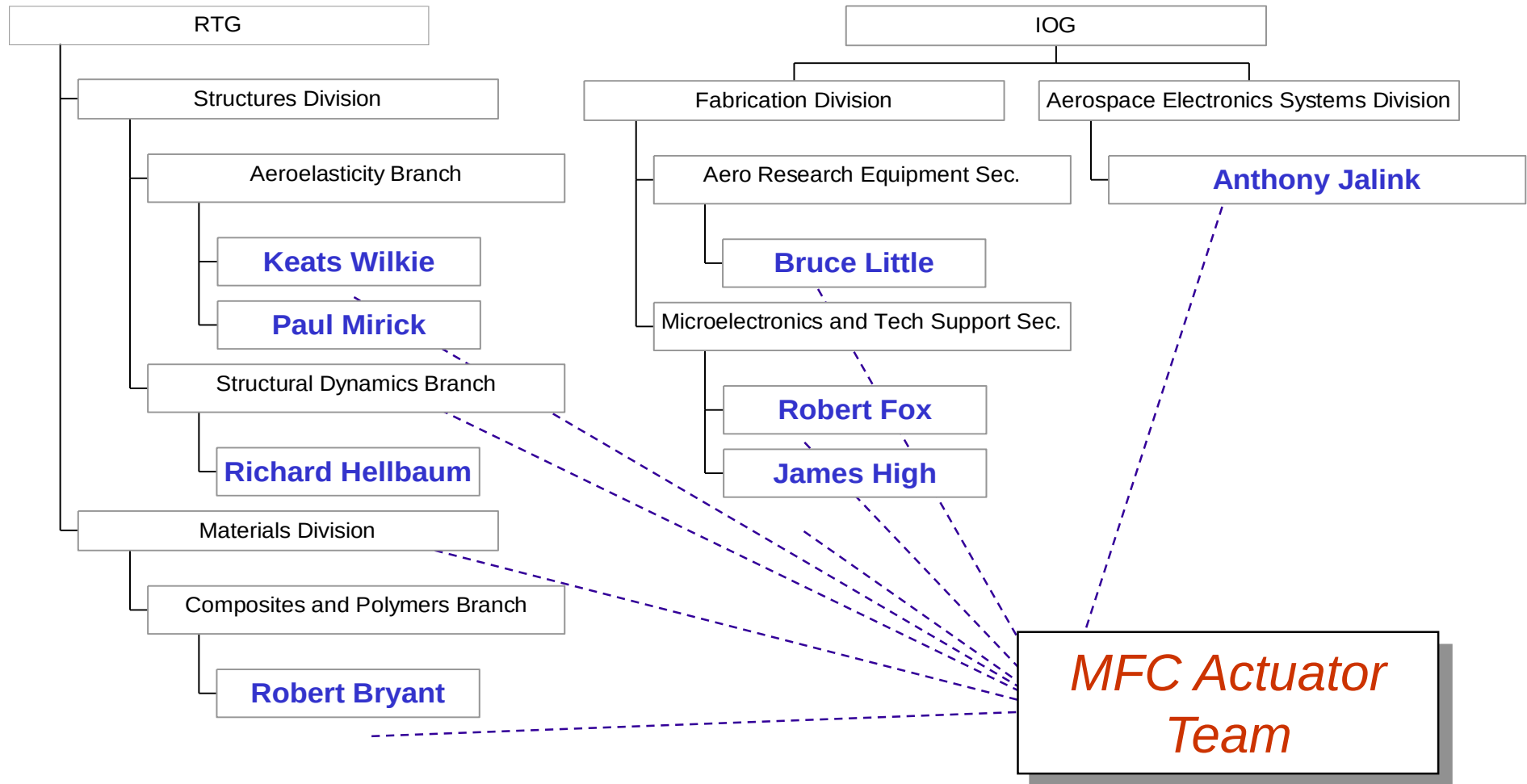
+

*Fibers encased in
protective epoxy matrix*

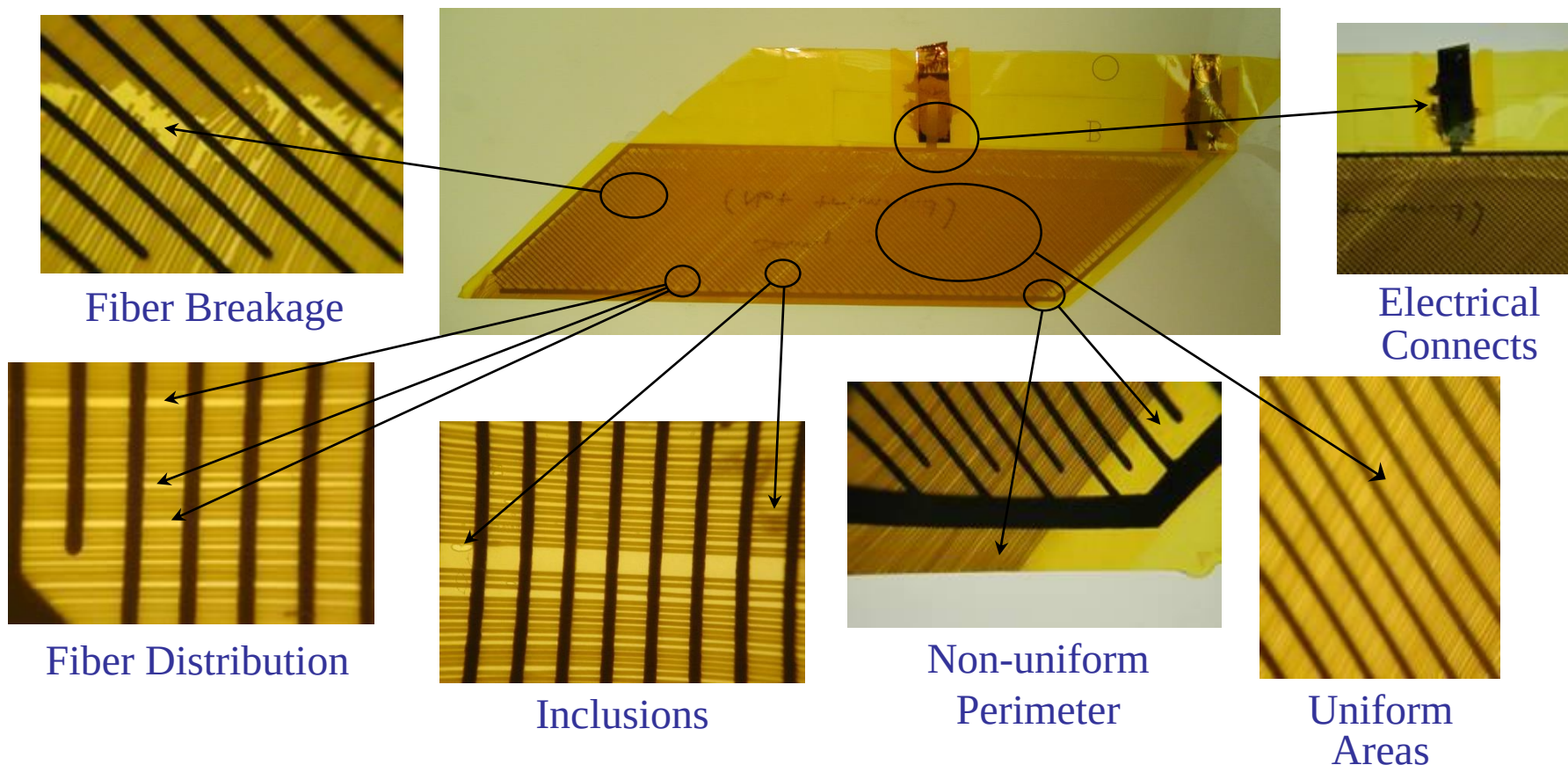
*Interdigitated
electrodes on
packaging film*



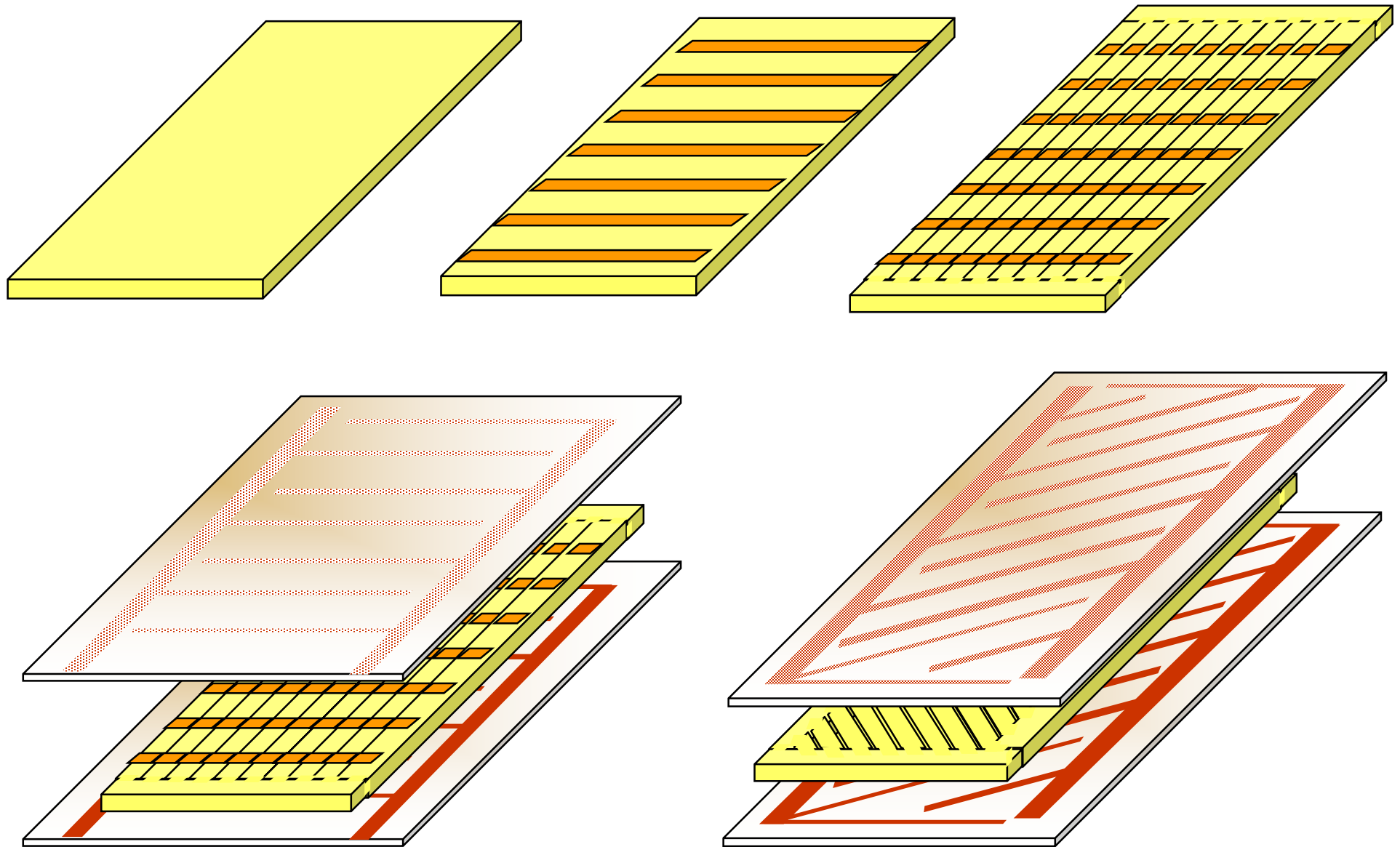
MFC Actuator Design Team



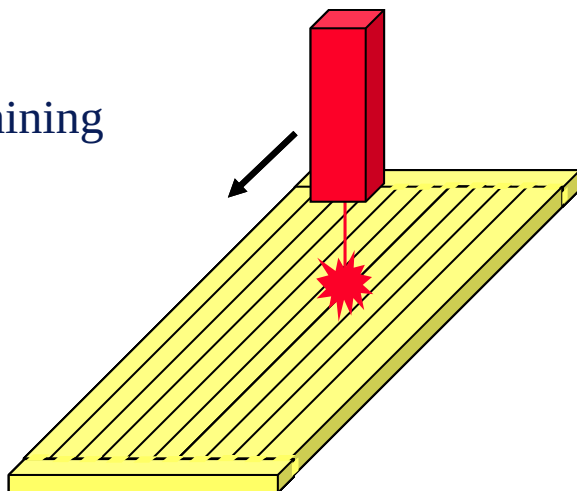
NASA Langley Research Center (LaRC), ca. December 1997



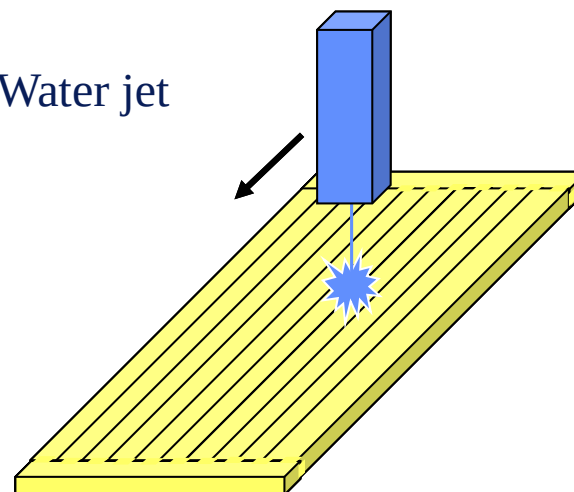
Leads to a Wide Variance in Electro-Mechanical Properties



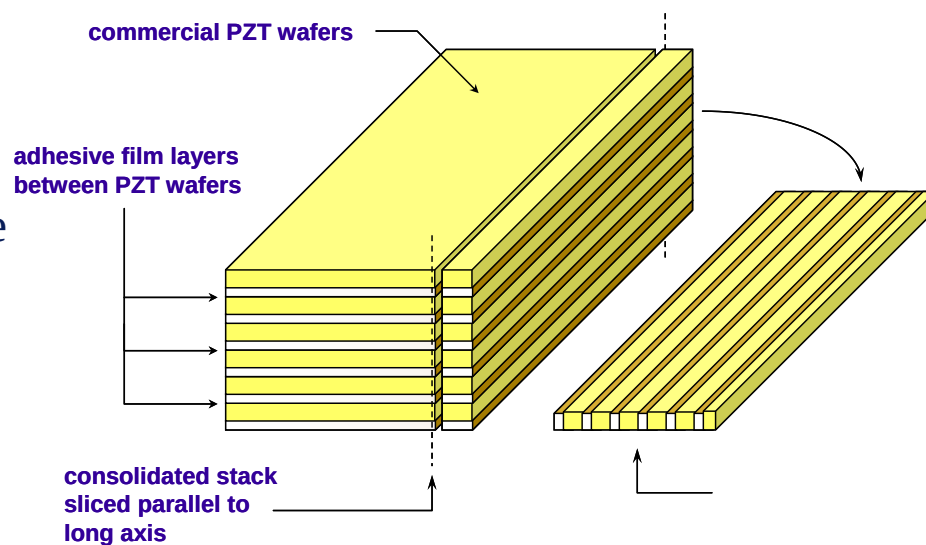
1. Laser machining

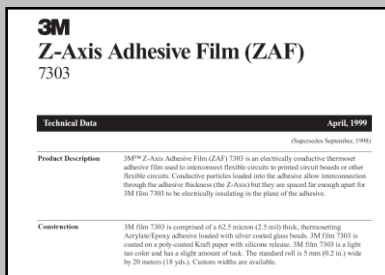
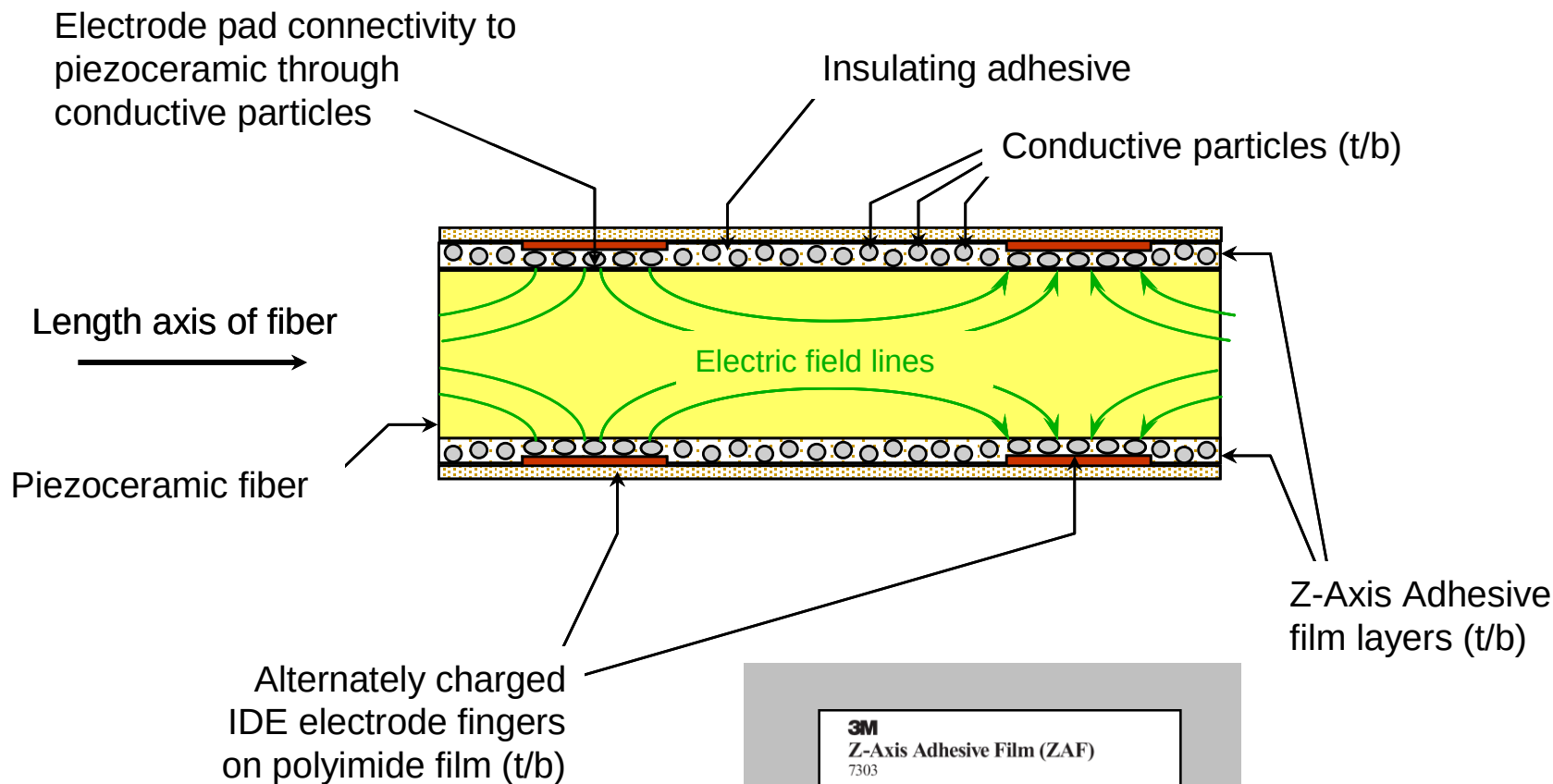


2. Water jet

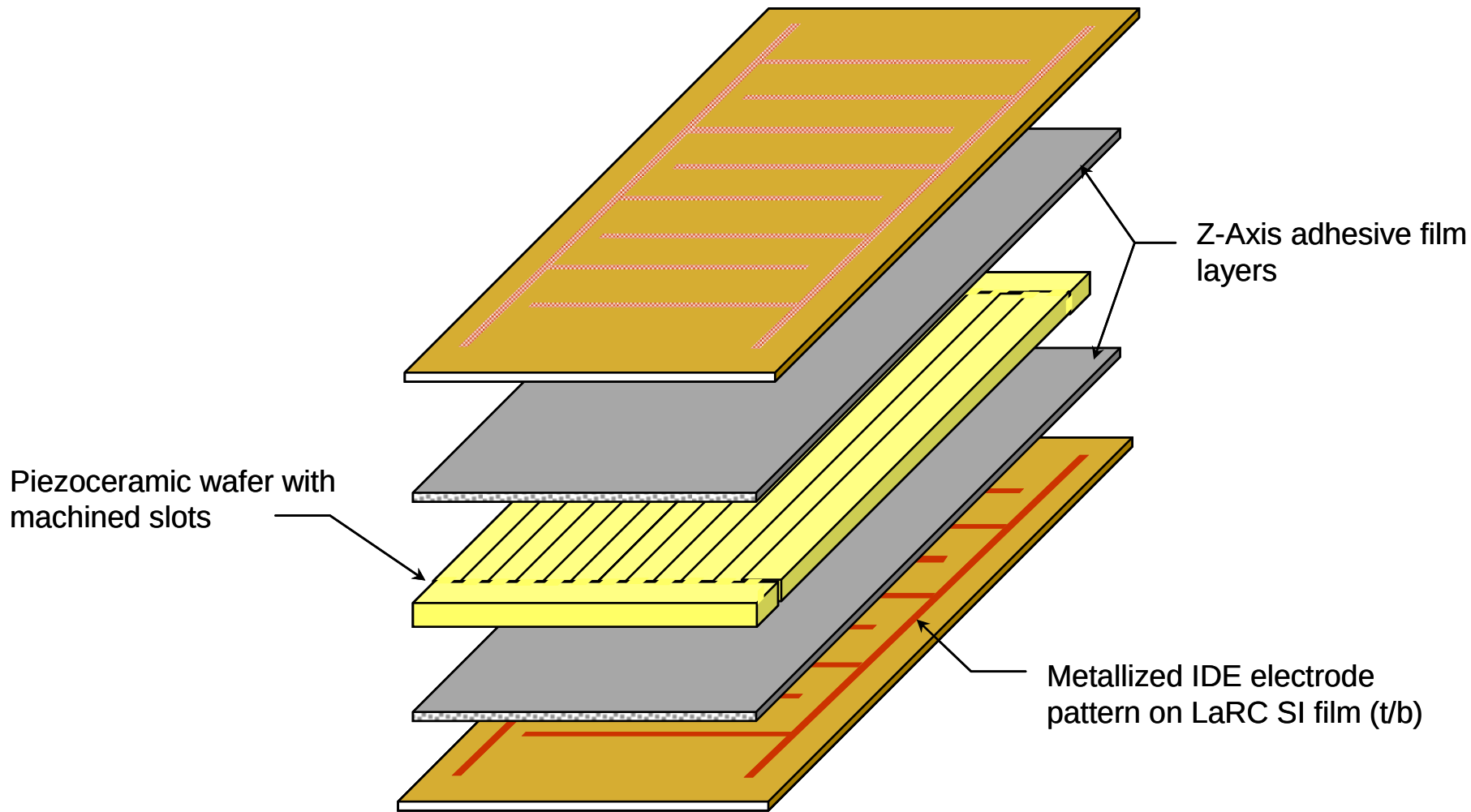


3. Stack and slice





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

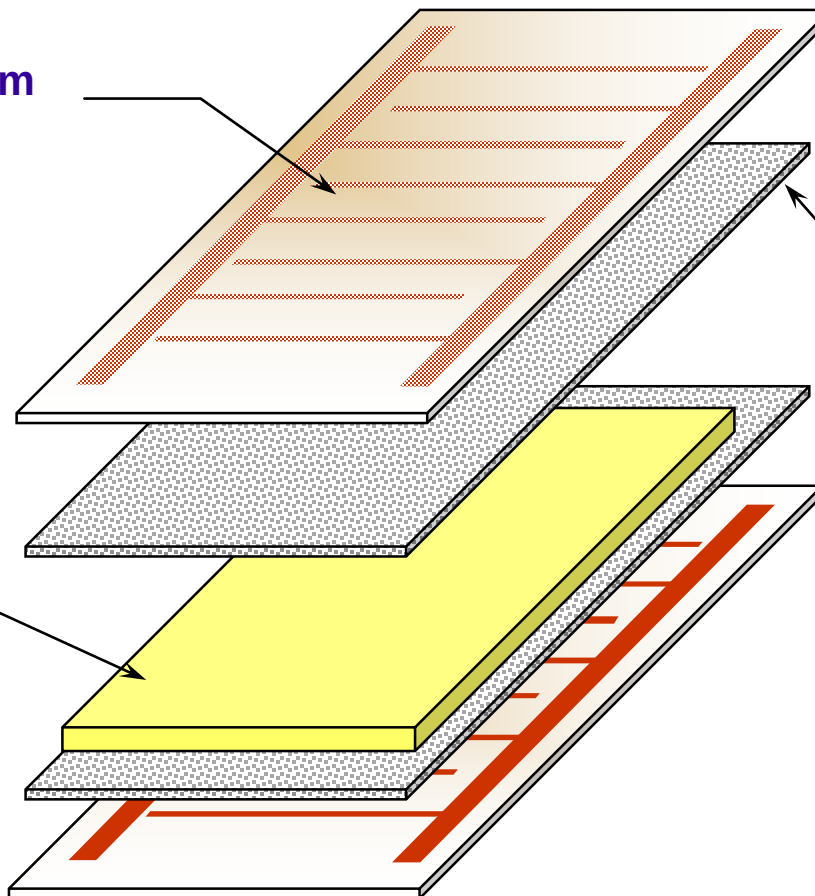


Interdigitated electrode pattern on polyimide film (t/b)

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

Monolithic PZT wafer

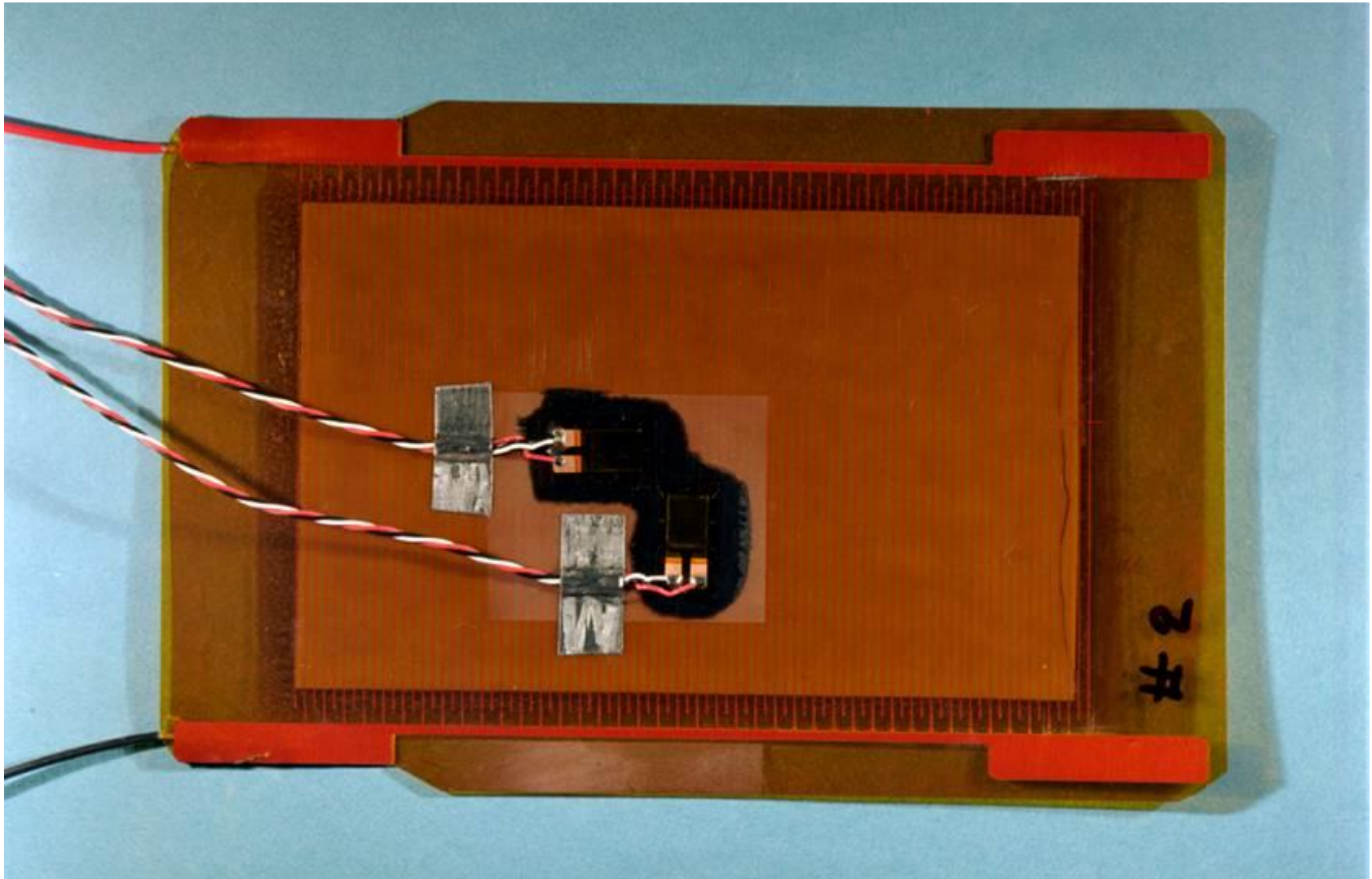
Electrode rails not in direct contact with ceramic. (Eliminates cracking due to nonuniform field near rails.)



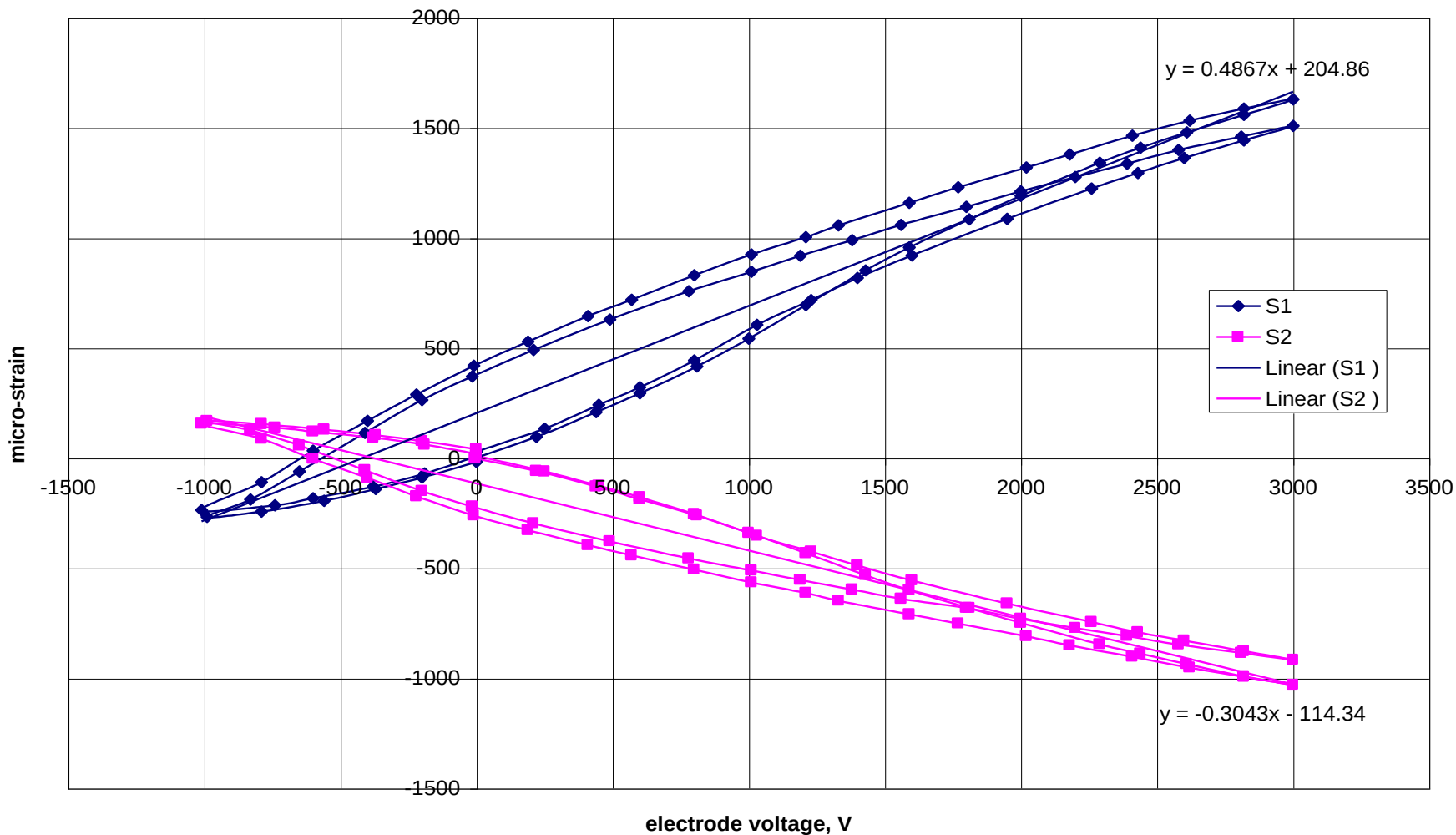
Electrode attachment with either:

- (a) anisotropically conductive adhesive,
- (b) structural epoxy with starved bond-line between electrodes and PZT

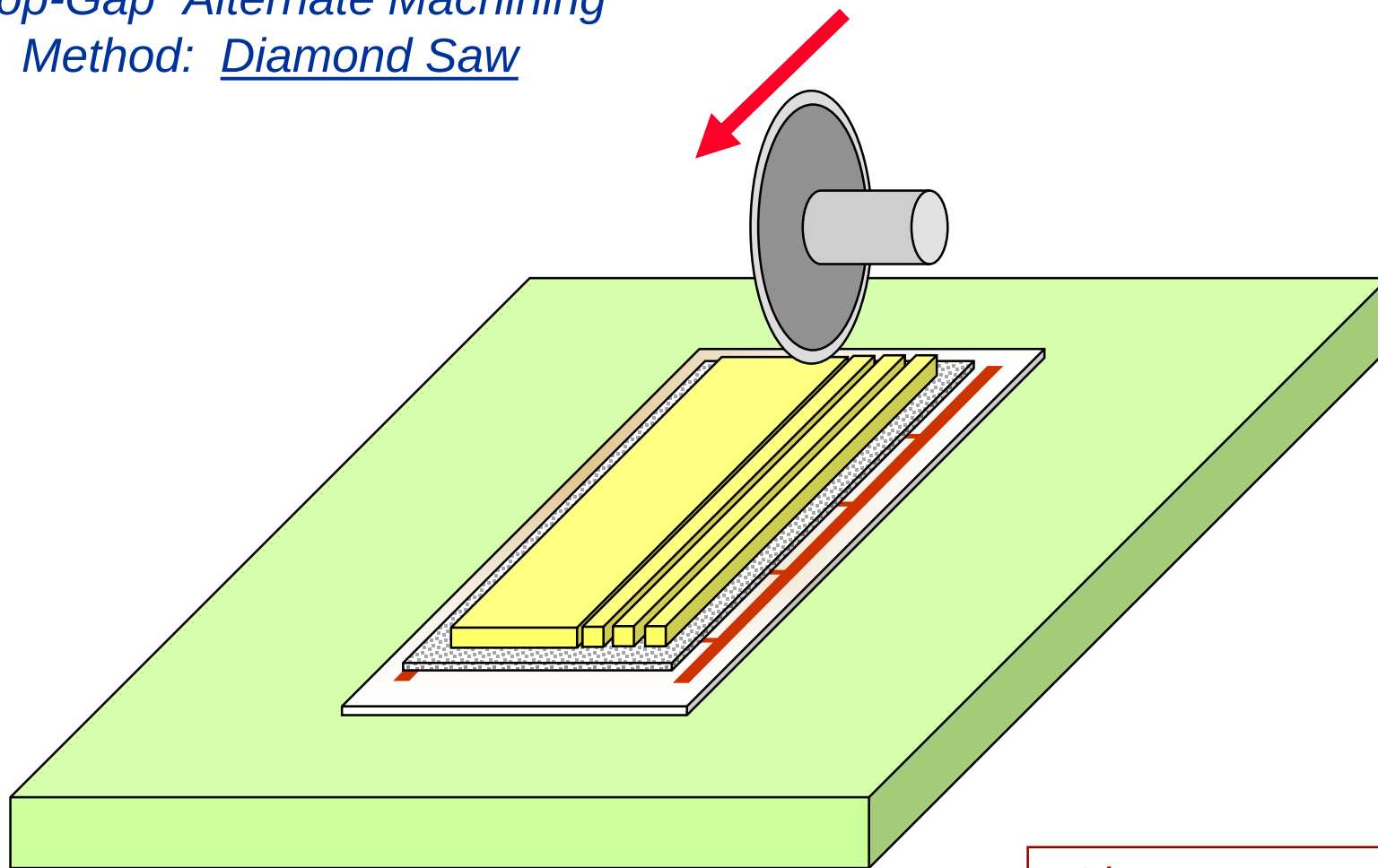
Reduces operating voltage by enabling direct electrical contact of electrodes and piezoceramic



LAFC-0-08a: free-displacement test (rep cycle)

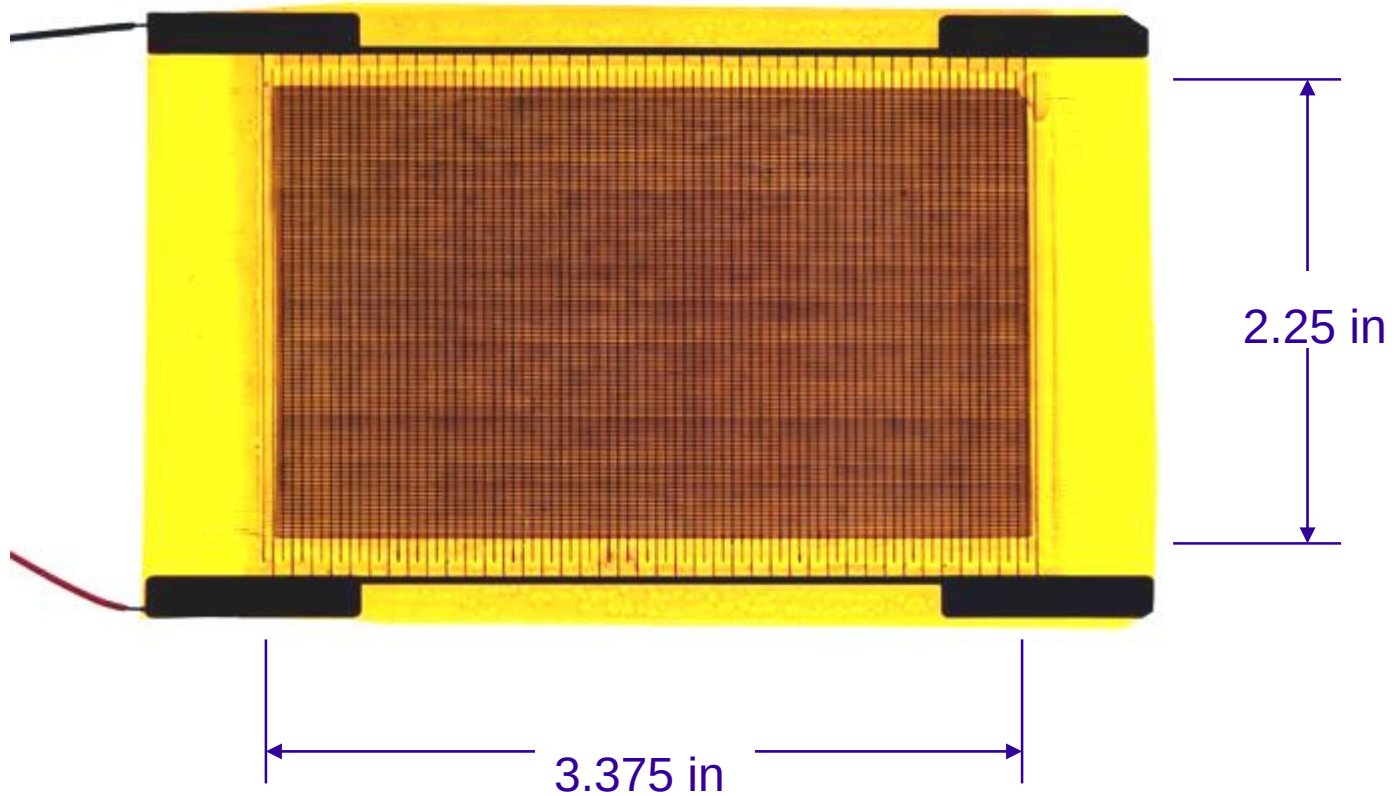


*"Stop-Gap" Alternate Machining
Method: Diamond Saw*

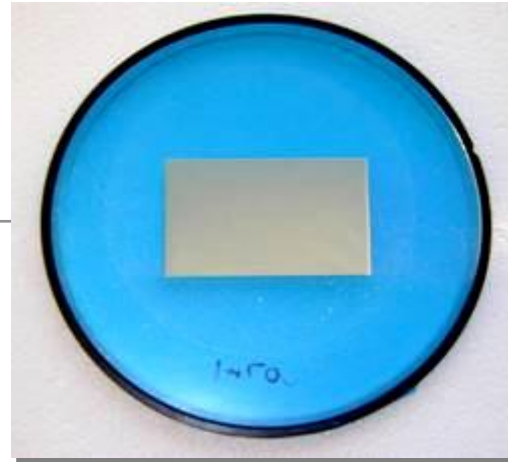


*4 hours to complete one
3.375 x 2.25 in wafer!*

Machined PZT Fiber Prototype: Actuator thickness = 0.011



*Semiconductor wafer
dicing saw*



*1. Ceramic wafer on
grip-tape frame*

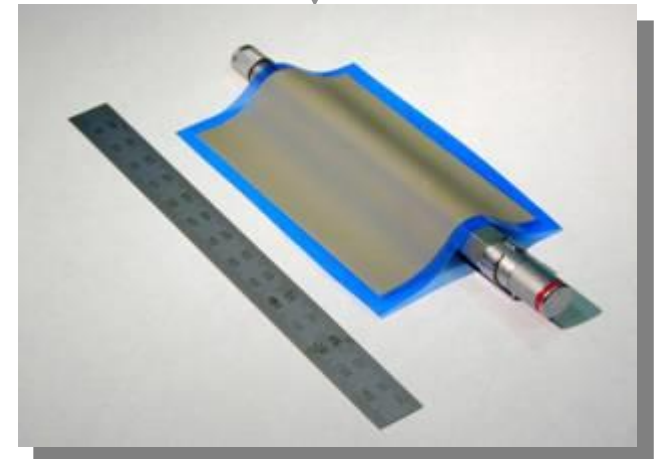
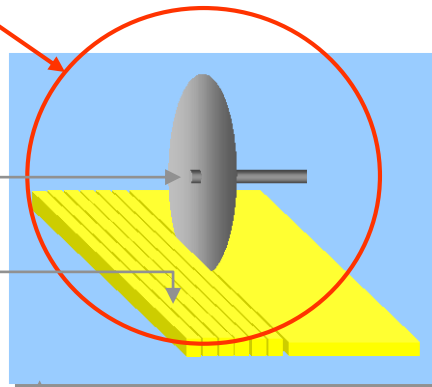


*2. Wafer and grip-tape frame
positioned for dicing*

*Diamond saw blade
(1 - 3 mil thick)*

*Piezoceramic wafer
(5 - 9 mil thick)*

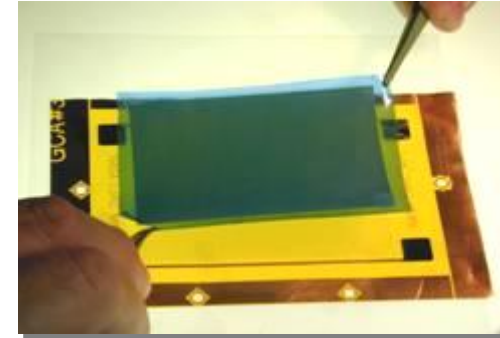
*Polymer grip film
(5 mil thick)*



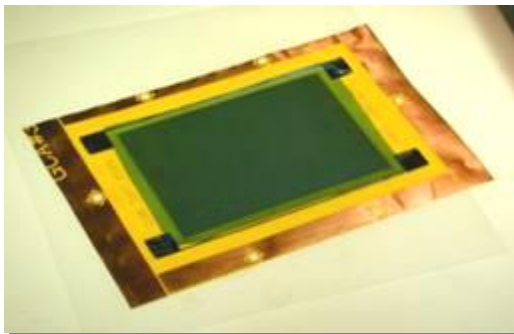
3. Completed piezoceramic fiber sheet



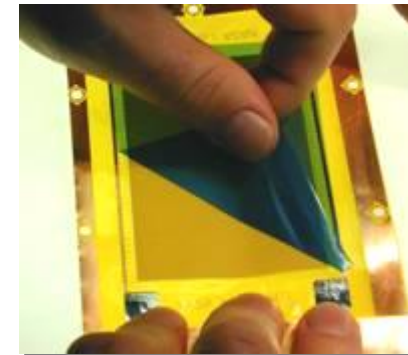
a) *Preparation of bottom electrode film with epoxy adhesive.*



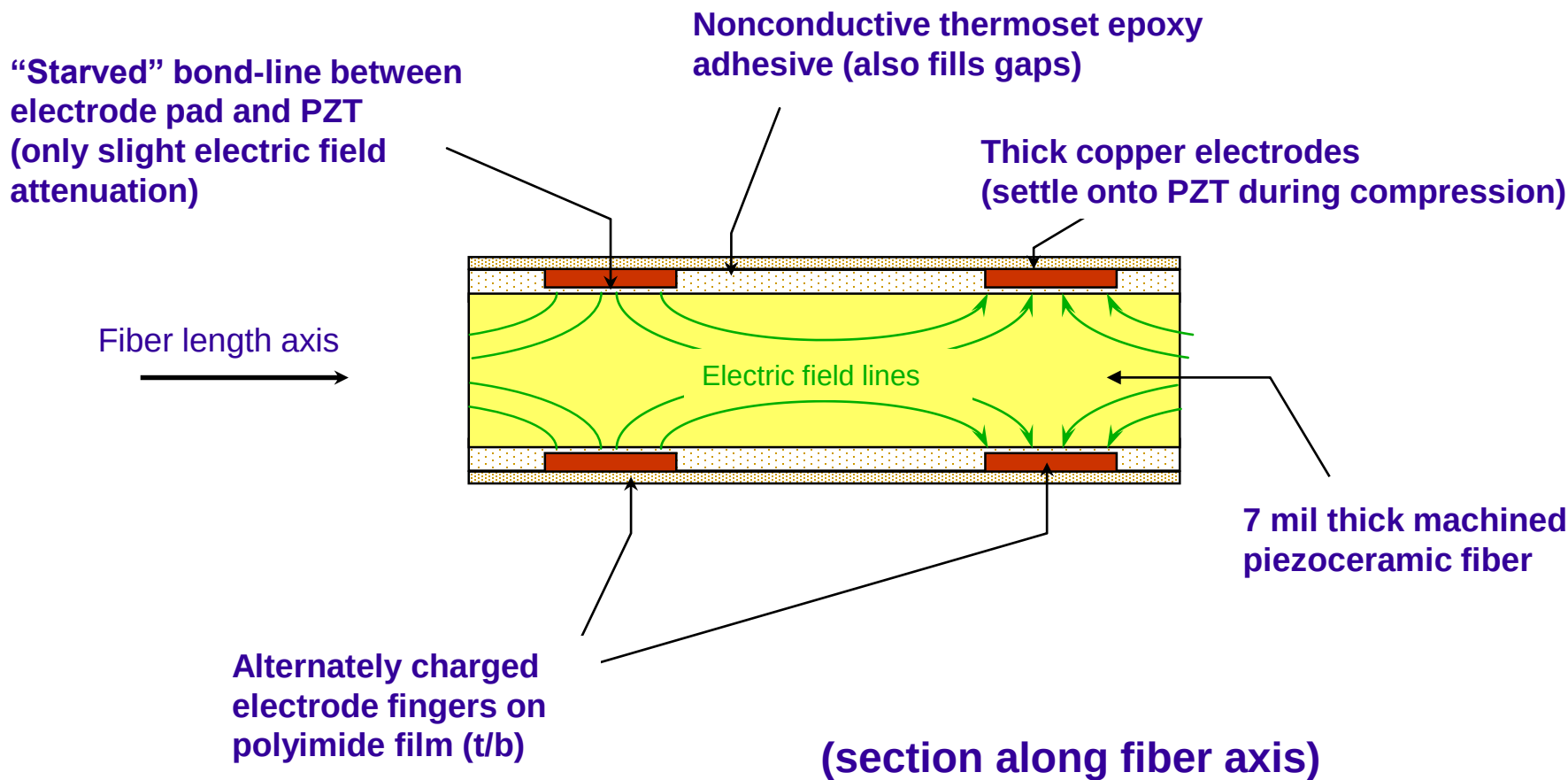
b) *Placement of fiber sheet on electrode film.*



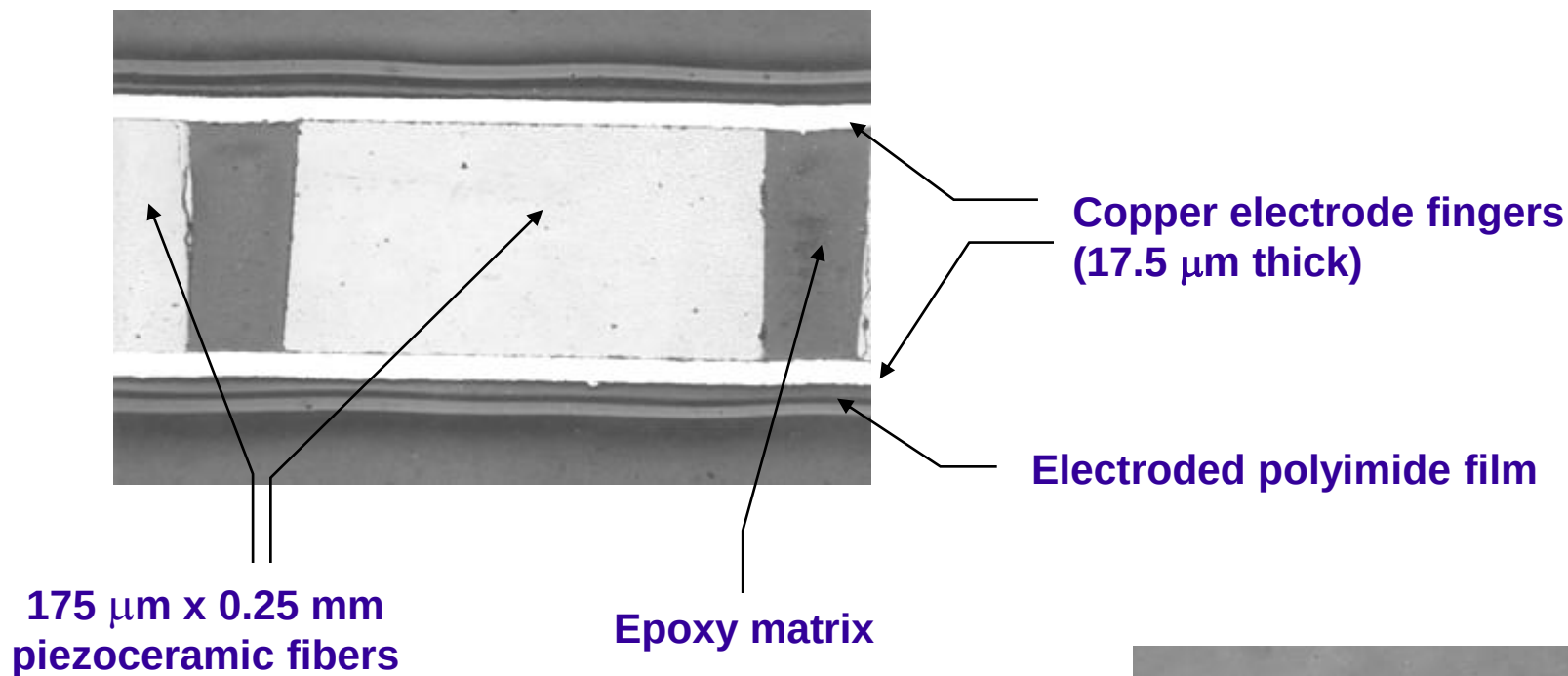
c) *Fiber sheet and electrode film after heat tacking.*



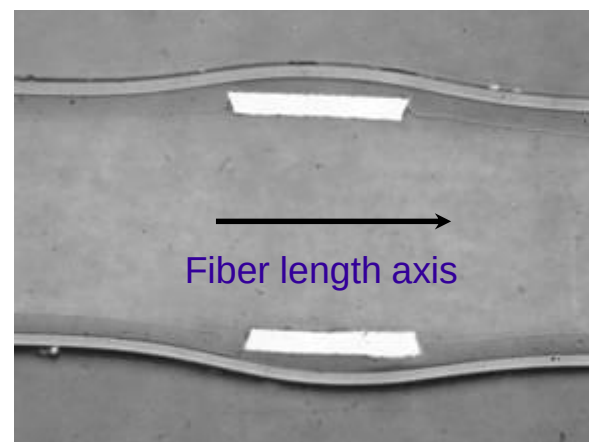
d) *Removal of polymer carrier film from transferred piezoceramic fibers.*



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

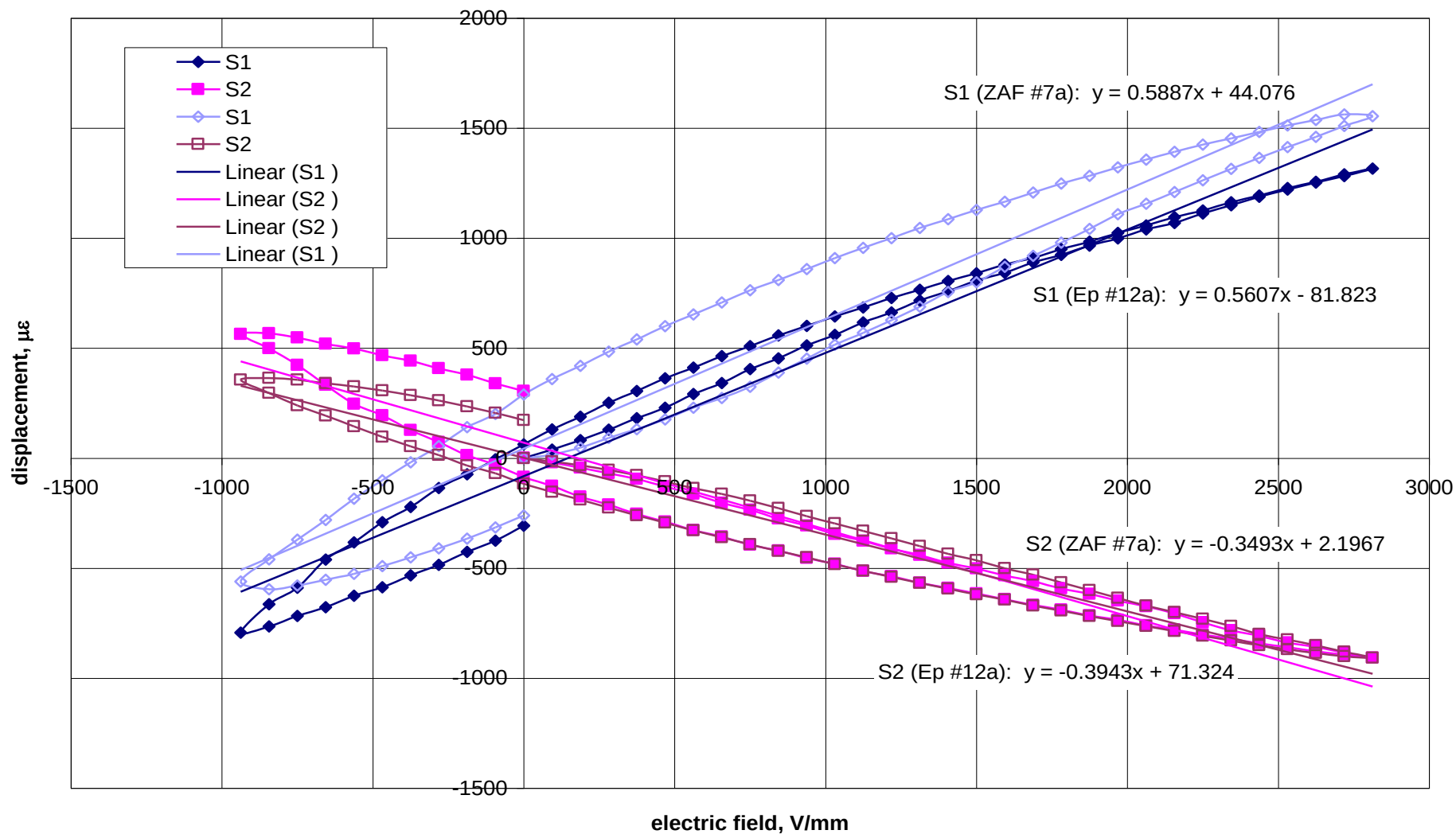


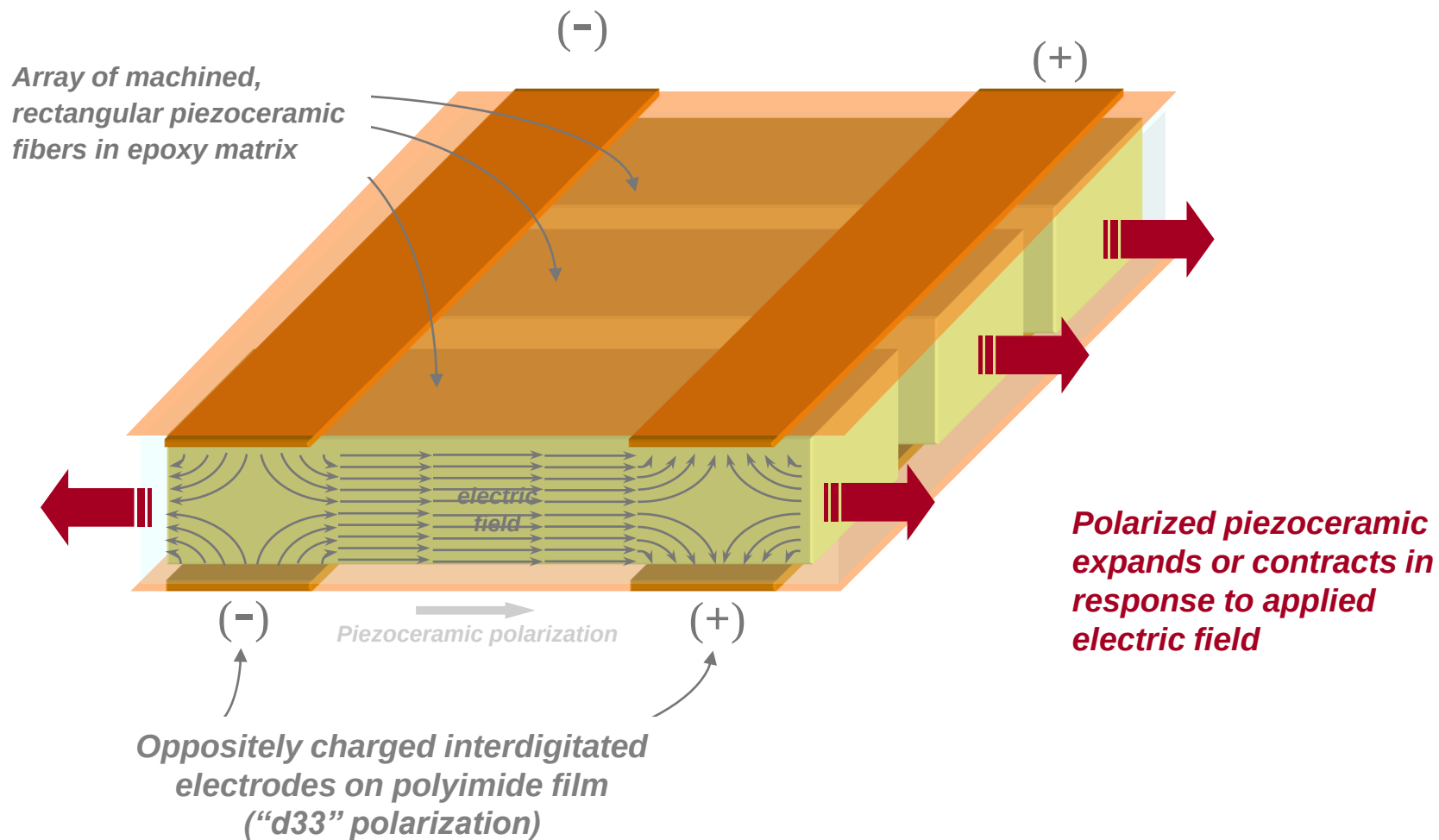
(A-A) Microphotograph across fiber axis.



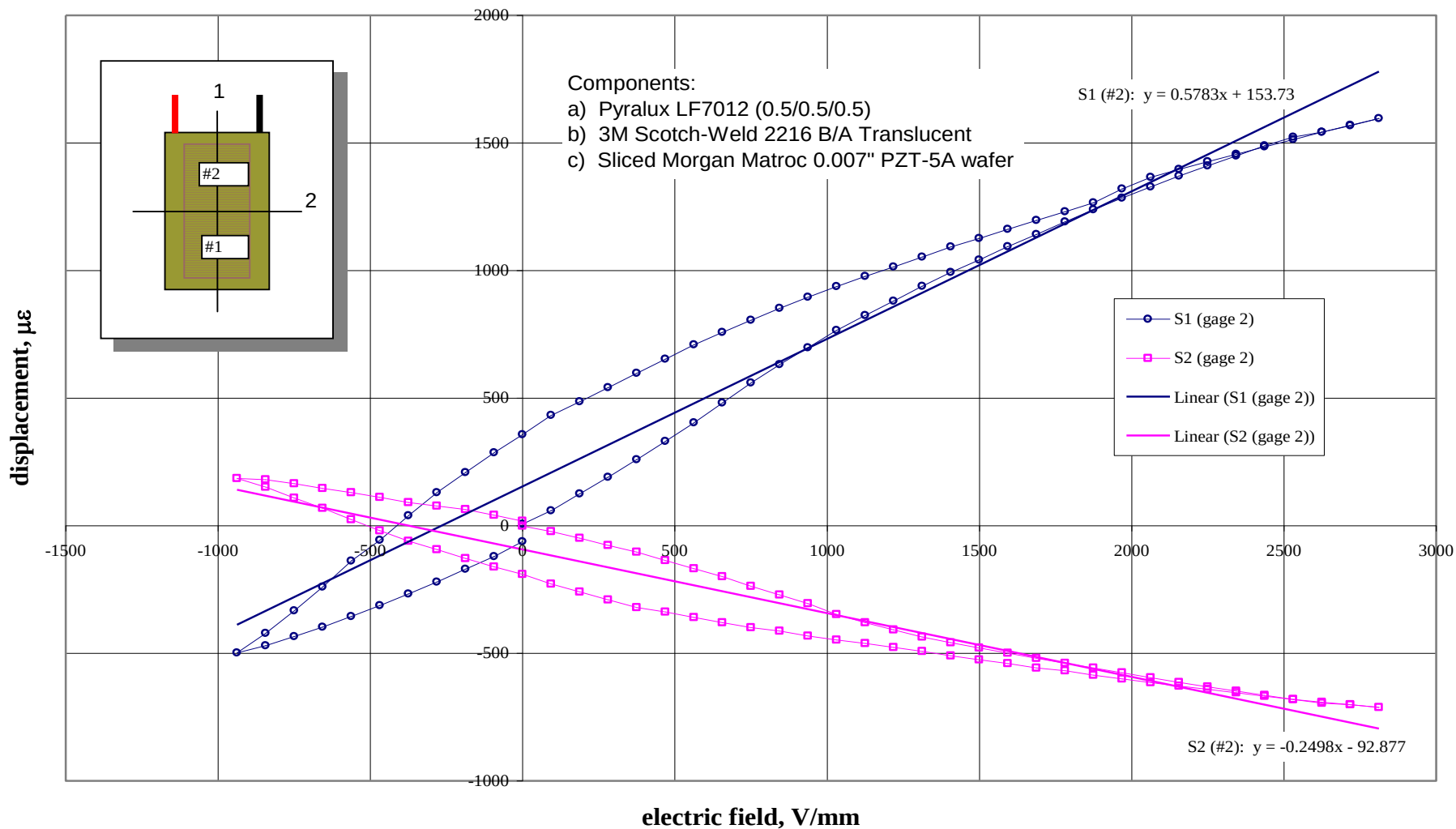
(B-B) Microphotograph along fiber axis.

Reference Actuators: ZAF versus Epoxy Electrode Attachment





Specimen #19: Free-displacement test





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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Vehicle Technology Directorate
Langley Research Center, Hampton, Virginia

June, 2003



(12) **United States Patent**
Wilkie et al.

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

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

6,747,292 A 5/1988 Robinson 26/25.35

(List continued on next page.)

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

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **09/436,677**

(22) Filed: **Oct. 28, 1999**

(65) **Prior Publication Data**

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(51) Int. Cl.⁷ **28/25.35; 26/34; 28/595;**

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33/0.299; 33/0.300; 33/0.301;

33/0.303; 33/0.304; 33/0.305; 33/0.306; 33/0.307; 33/0.308;

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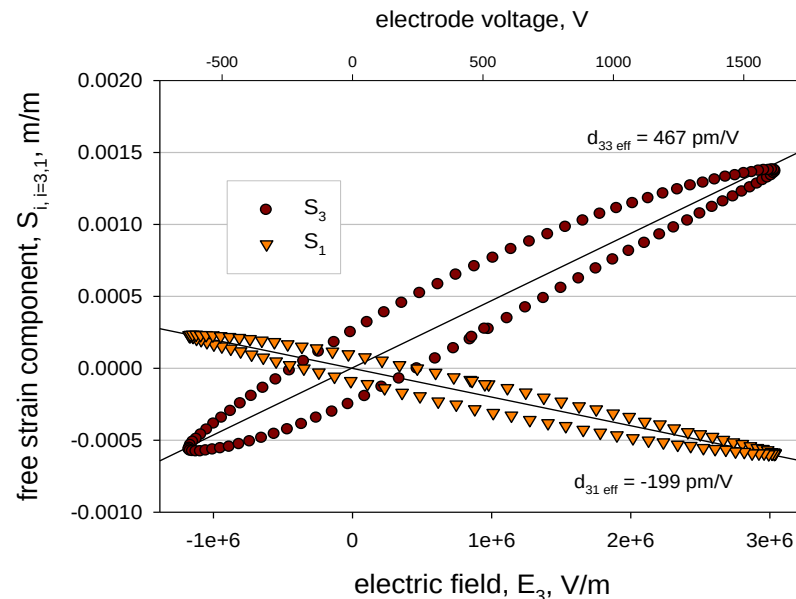
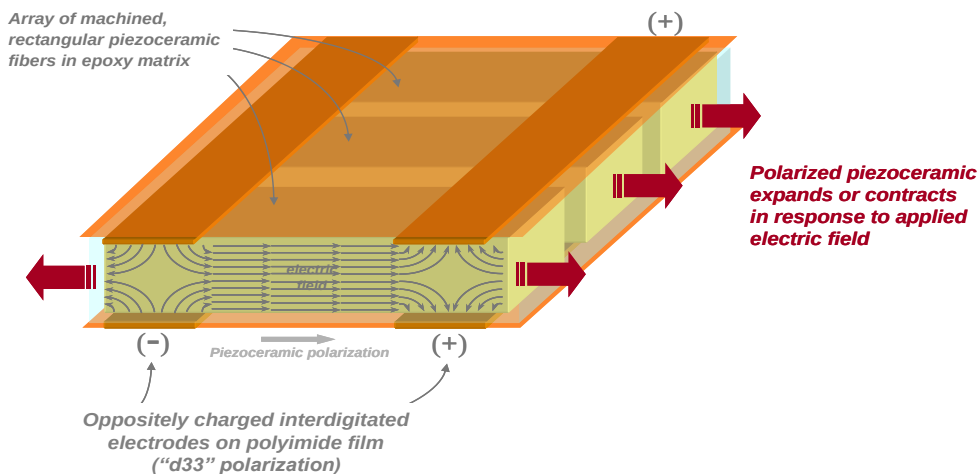
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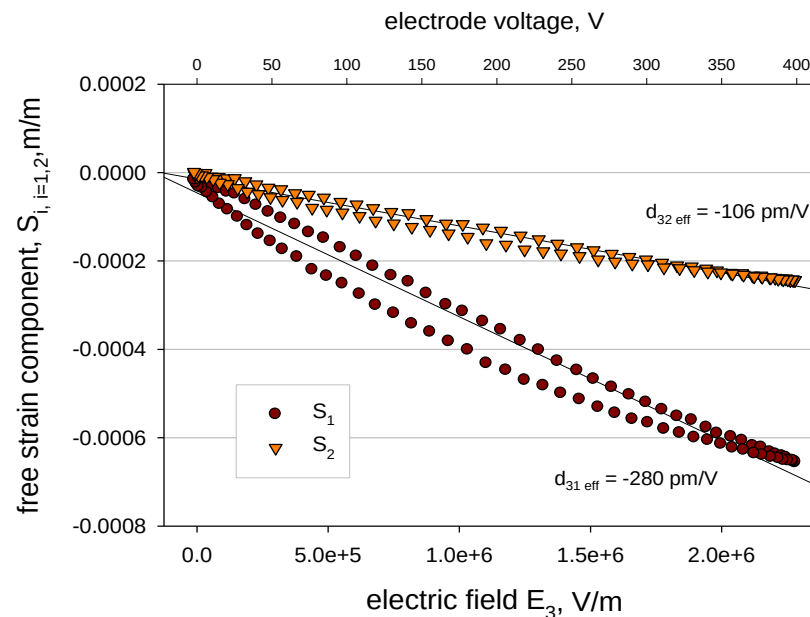
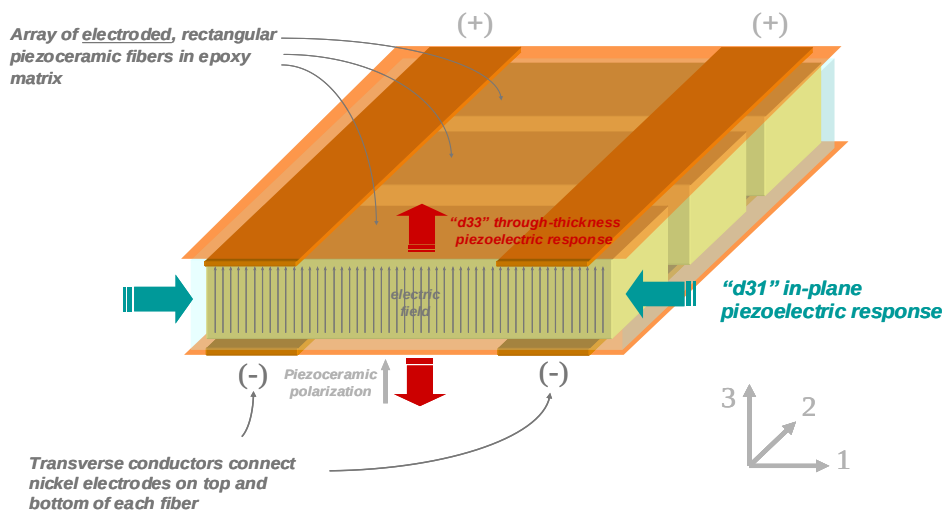
LaRC-MFC: 2000 R&D100 Award Winners

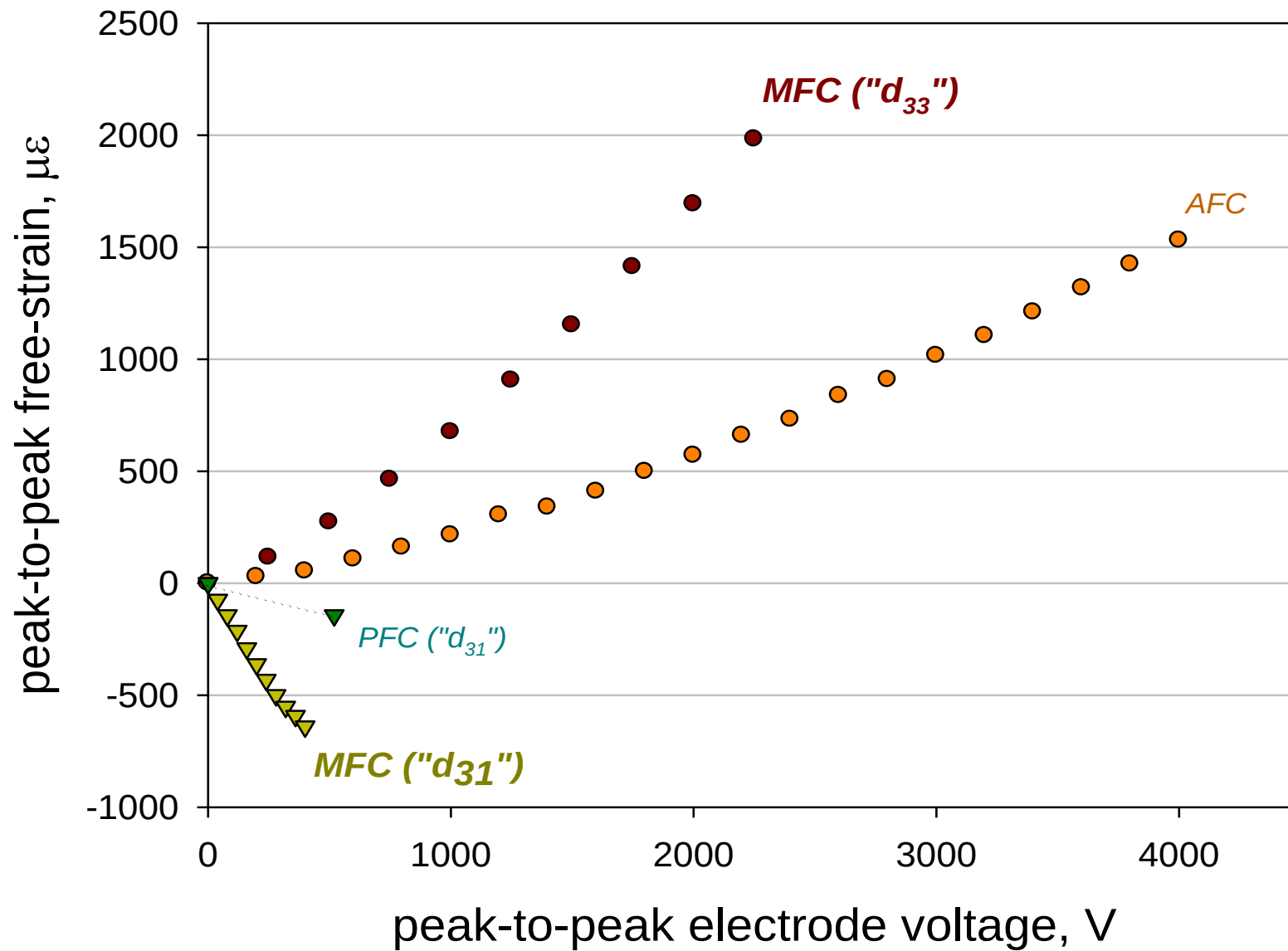


Standard “ d_{33} ” polarization

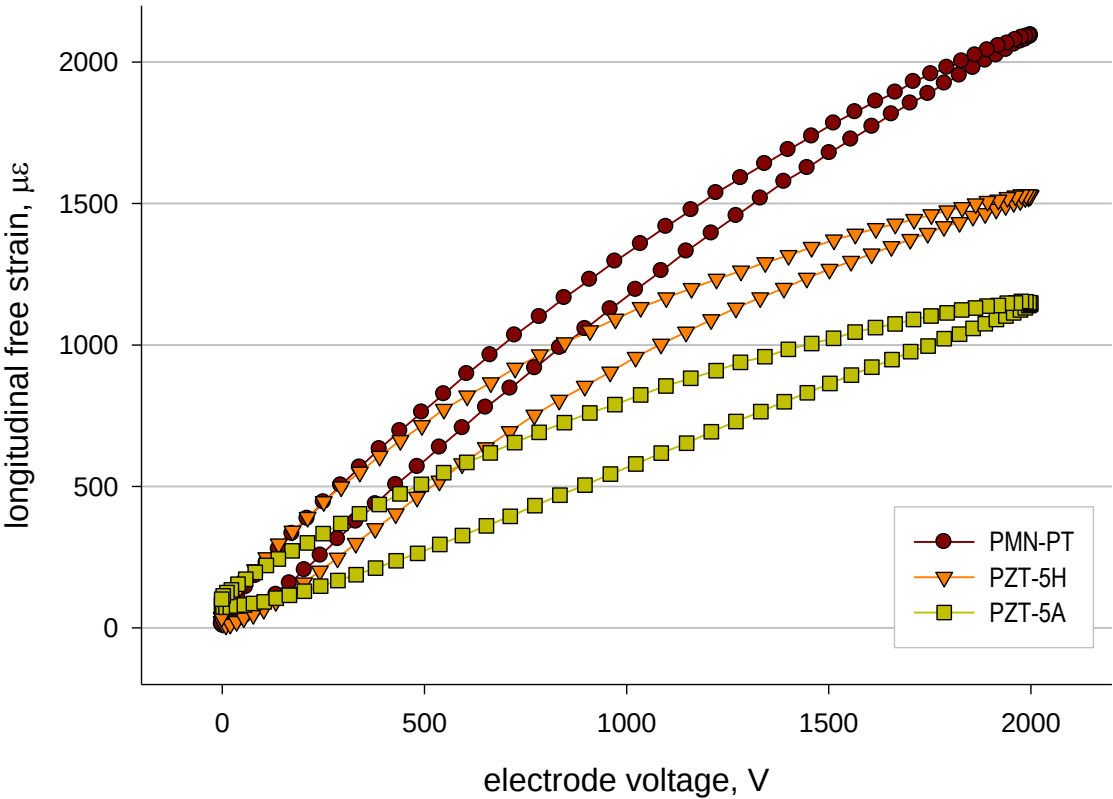


Alternate “ d_{31} ” polarization

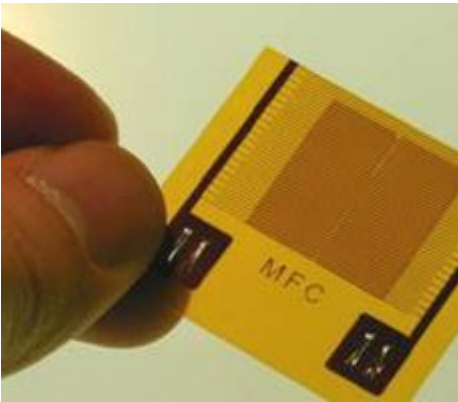




Unipolar Drive Results



20 mm MFC Test Specimens



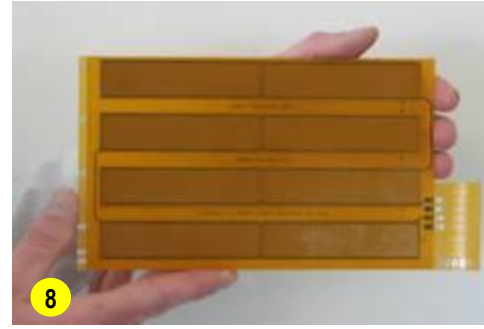
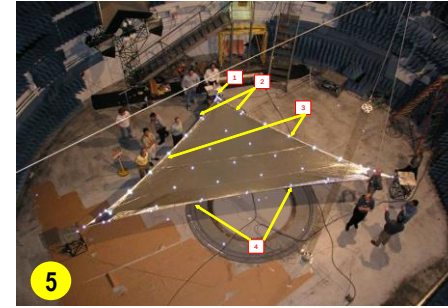
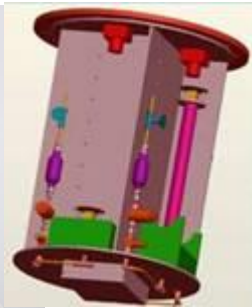
material	$S_3/S_{3,PZT-5A}^\dagger$	$\bar{d}_{33}/\bar{d}_{33,PZT-5A}$	$\Delta\%_{3-dr}^\ddagger$
PZT-5A	1.0	1.0	-
PZT-5H	1.40	1.66	+18.6%
PMN-PT	1.96	4.88	+149%

$$\bar{d}_{33} = \frac{d_{33,f}}{1 + \frac{\phi_m}{\phi_f} \frac{S_{33,f}^E}{S_{33,m}^E}}$$

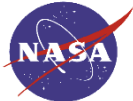
material	K_3^T (1kHz)	k_{33}	d_{33} , pm/V	d_{31} , pm/V	ρ , g/cm ³	s_{33}^E [†]	s_{11}^E	s_{13}^E	s_{44}^E
PZT-5A	1900	0.72	390	-190	7.8	18.8	16.4	-7.22	47.5
PZT-5H	3800	0.75	650	-320	7.8	20.7	16.5	-9.1	43.5
PMN-PT	7151	0.91	2285	-1063	8.05	86.5	59.7	-45.3	14.4

[†] elastic constants, s, 10⁻¹² m²/N

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



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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Ben Copeland

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Jim Linker

NASA Langley Research Center

Kathy Kuykendal

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