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# ***PowerFibers - Thin-Film Batteries on Fiber Substrate***

**Bernd J. Neudecker and Martin H. Benson**

***ITN Energy Systems,  
8130 Shaffer Parkway, Littleton, CO 80127, USA***

**DARPA Synthetic Multifunctional Materials (SMFM) Program  
Dr. Leo Christodoulou, DARPA, SMFM Program Manager  
Dr. Steven Fishman, ONR, COTR**



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# Report Documentation Page

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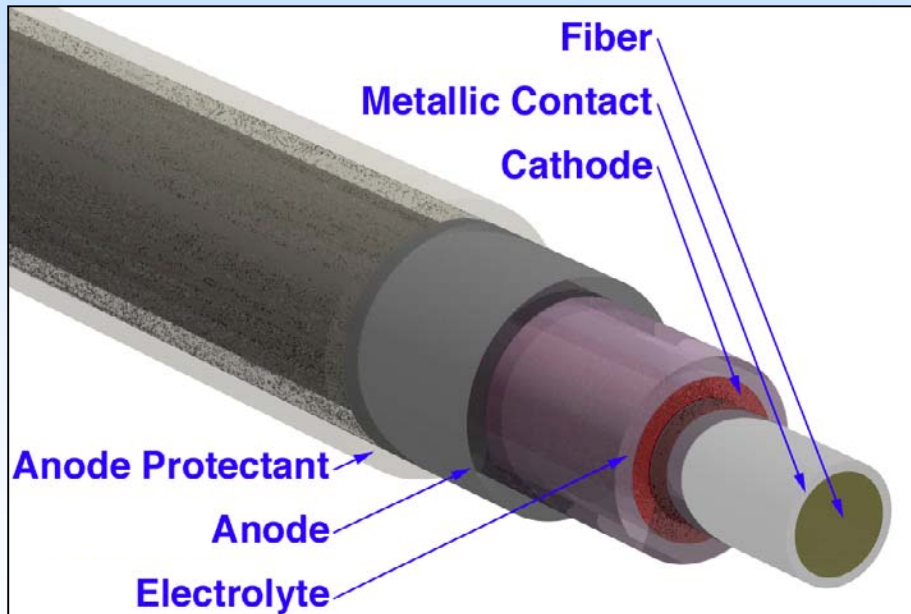
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# The Concept: PowerFiber $\Rightarrow$ PowerComposite

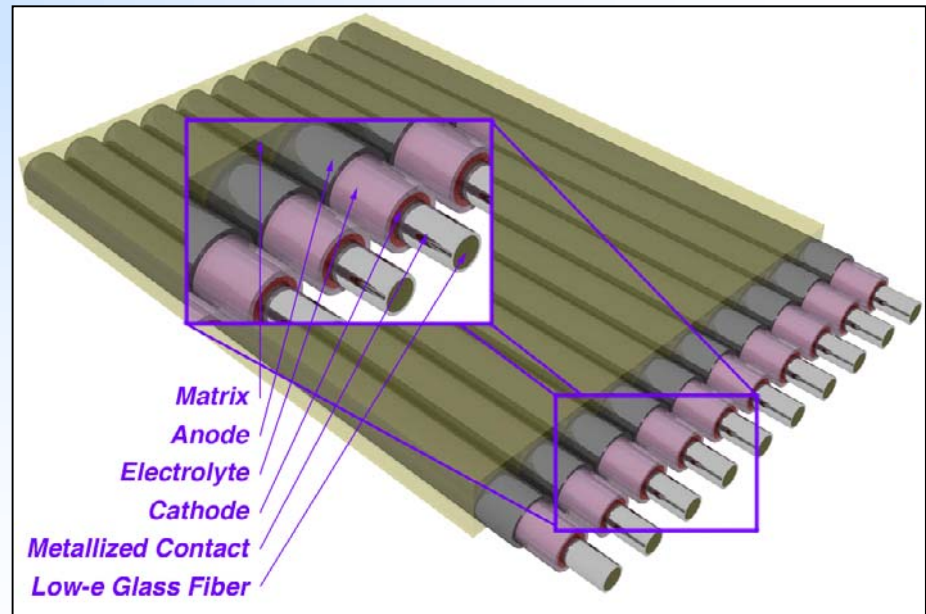
## ■ Objectives:

- 1) Fabricate solid-state thin-film batteries directly onto structural fibers
- 2) Incorporate these “PowerFibers” into structural composites and fabrics

### “PowerFiber”



### “PowerComposite”

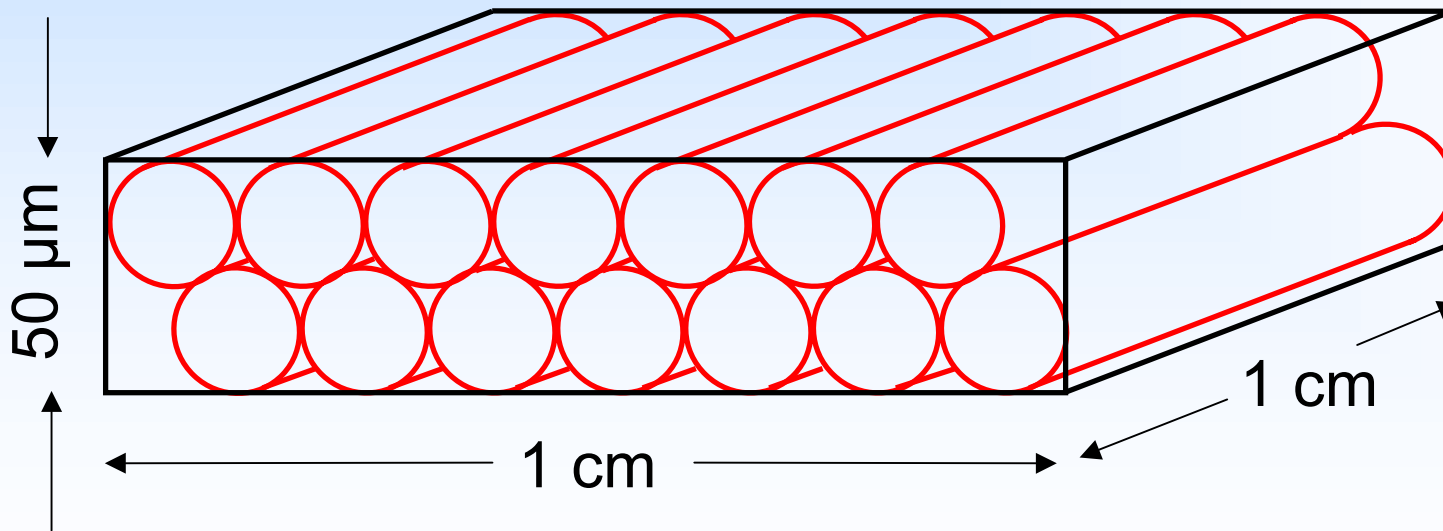


# Energy, Power (Thin-Film Batteries) = Proportional to Battery Area !

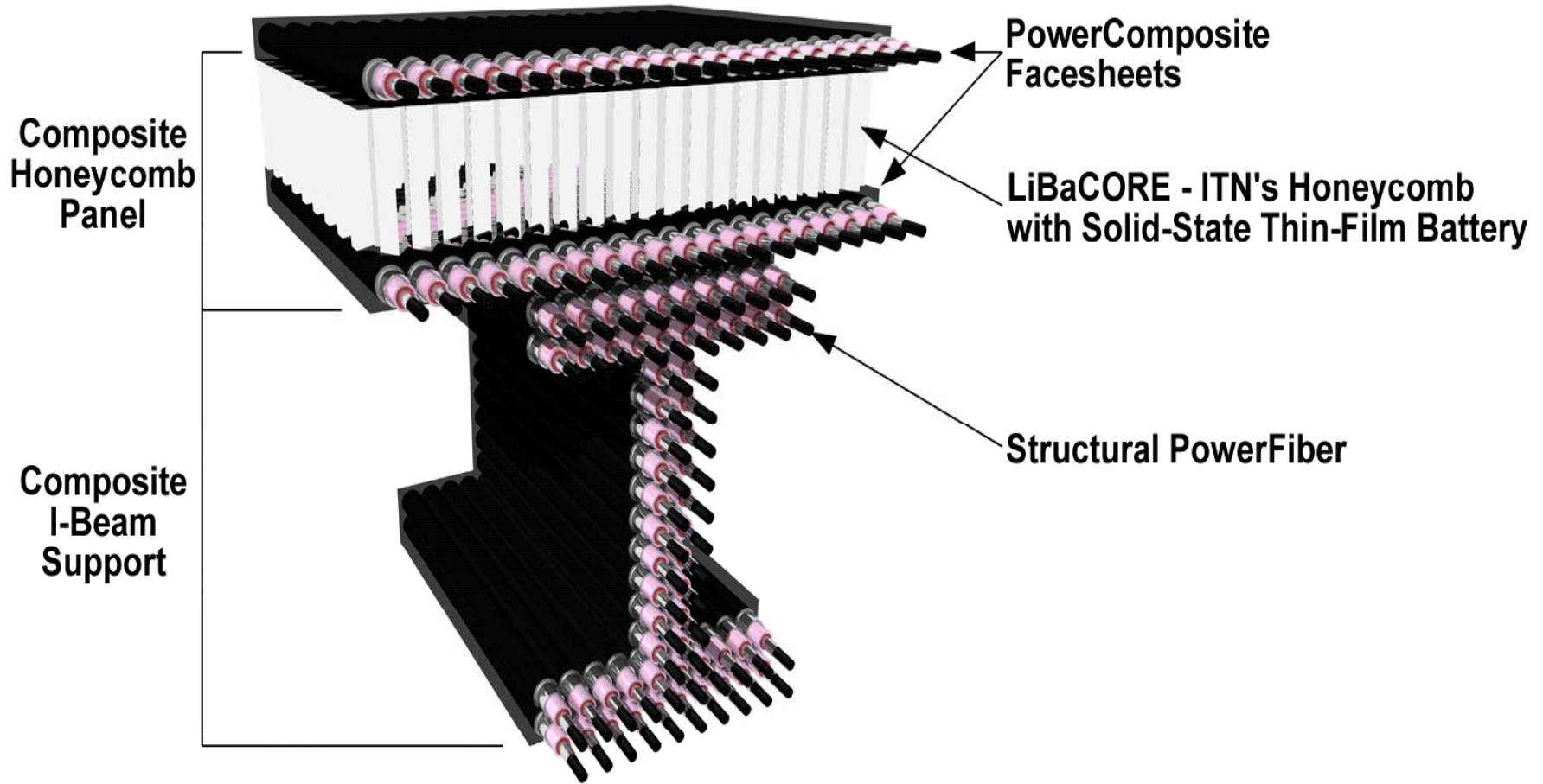


## ■ Substrate Area: Foil vs. *Fiber Stack*

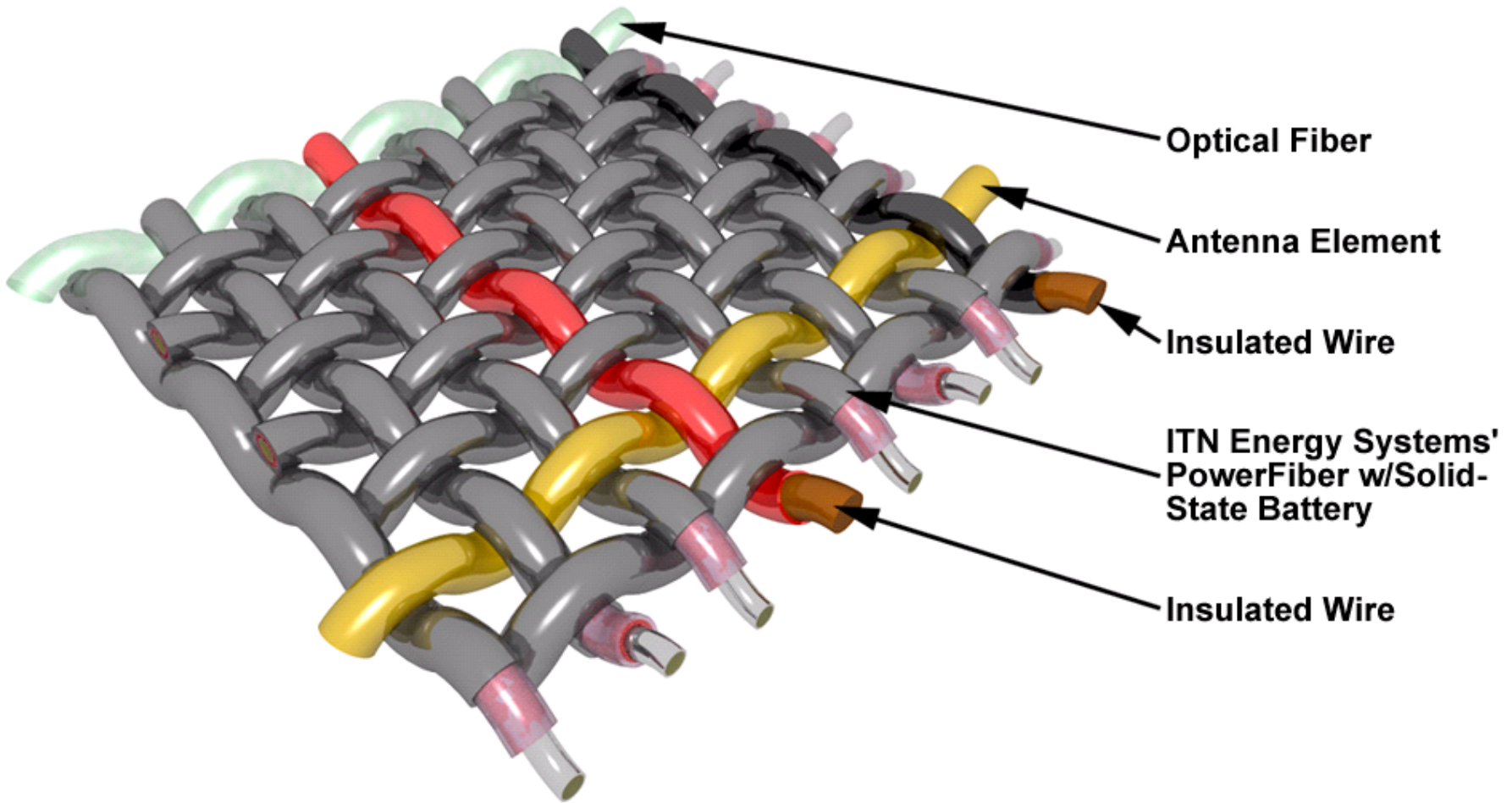
Double-sided foil substrate (50 $\mu\text{m}$ thick)	=	2 $\text{cm}^2$
1 Layer of fibers (50 $\mu\text{m}$ in dia.)	=	3.14 $\text{cm}^2$ ( 57% more area)
2 Layers of fibers (25 $\mu\text{m}$ in dia.)	=	6.28 $\text{cm}^2$ (214% more area)
3 Layers of fibers (17 $\mu\text{m}$ in dia.)	=	9.42 $\text{cm}^2$ (371% more area)



# PowerComposite Applications



# ITN's ElectroTextiles Concept: PowerFiber $\Rightarrow$ PowerWeave



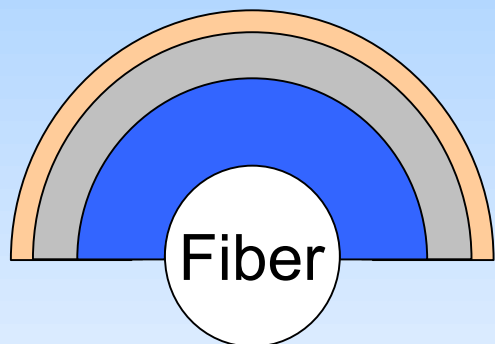
# "Li-Free" Battery Configurations

## Cathode (+) = Only Initial Li Source

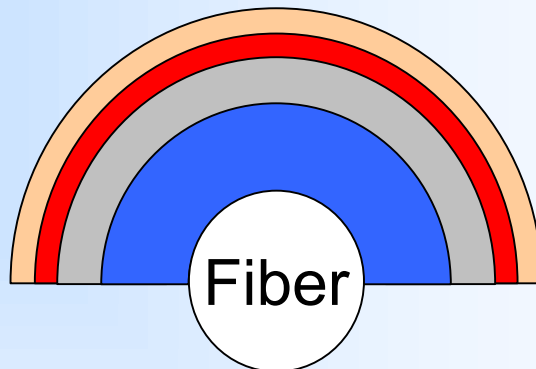


As-Fabricated

During Operation

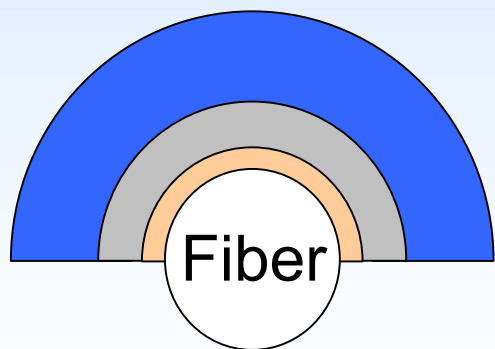


Charge  
Discharge

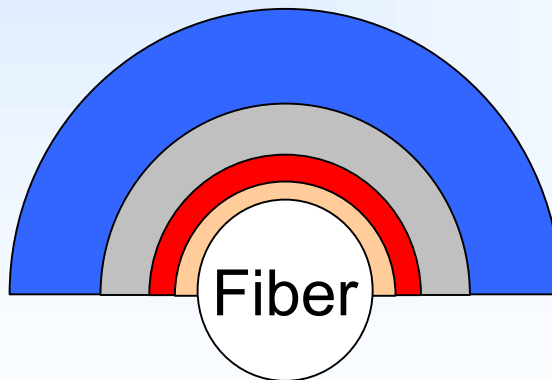


**"Li-Free"**

Cathode (+)  
Electrolyte  
Plated Li  
Cu acc (-)



Charge  
Discharge

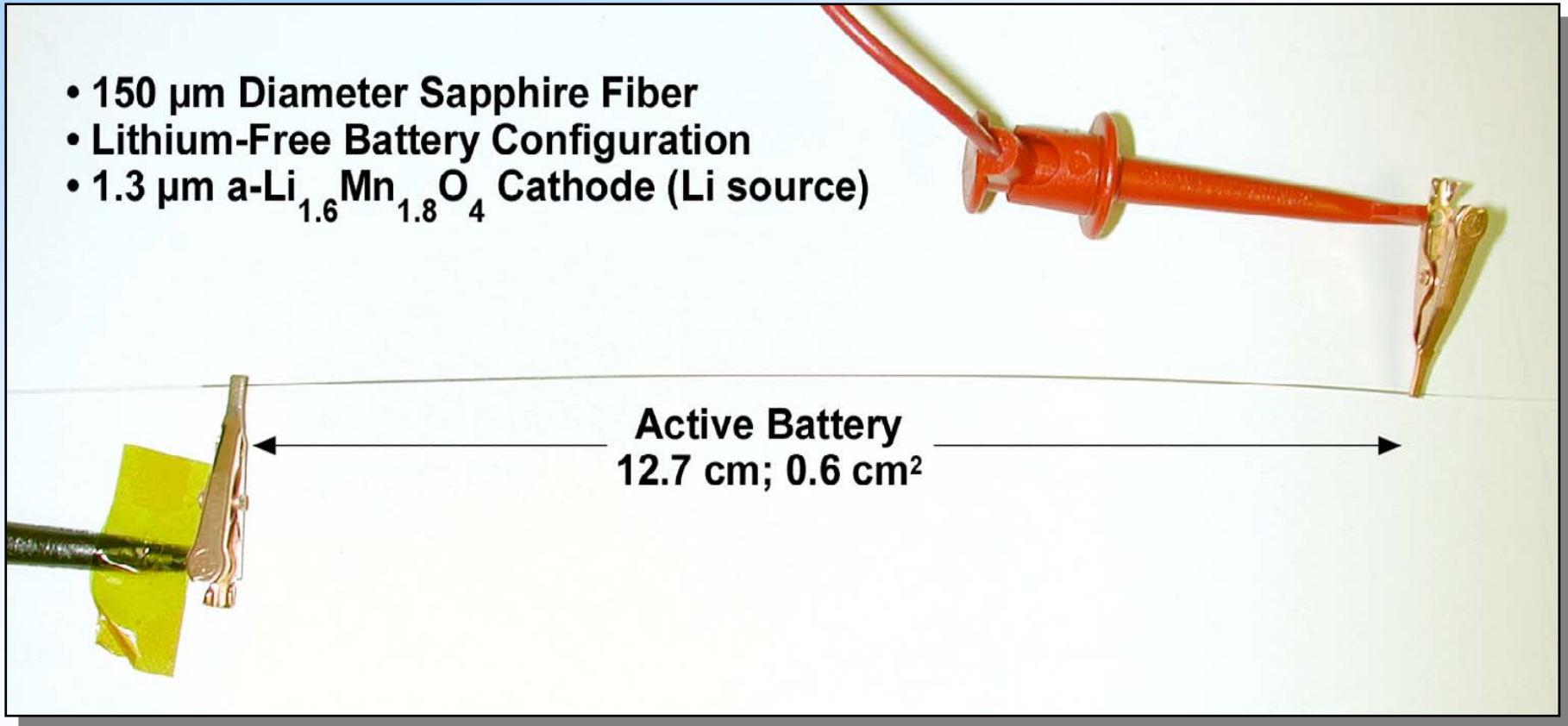


**"Buried Li-Free"**

# “Li-Free” PowerFiber on Sapphire - Electrochemical Testing -

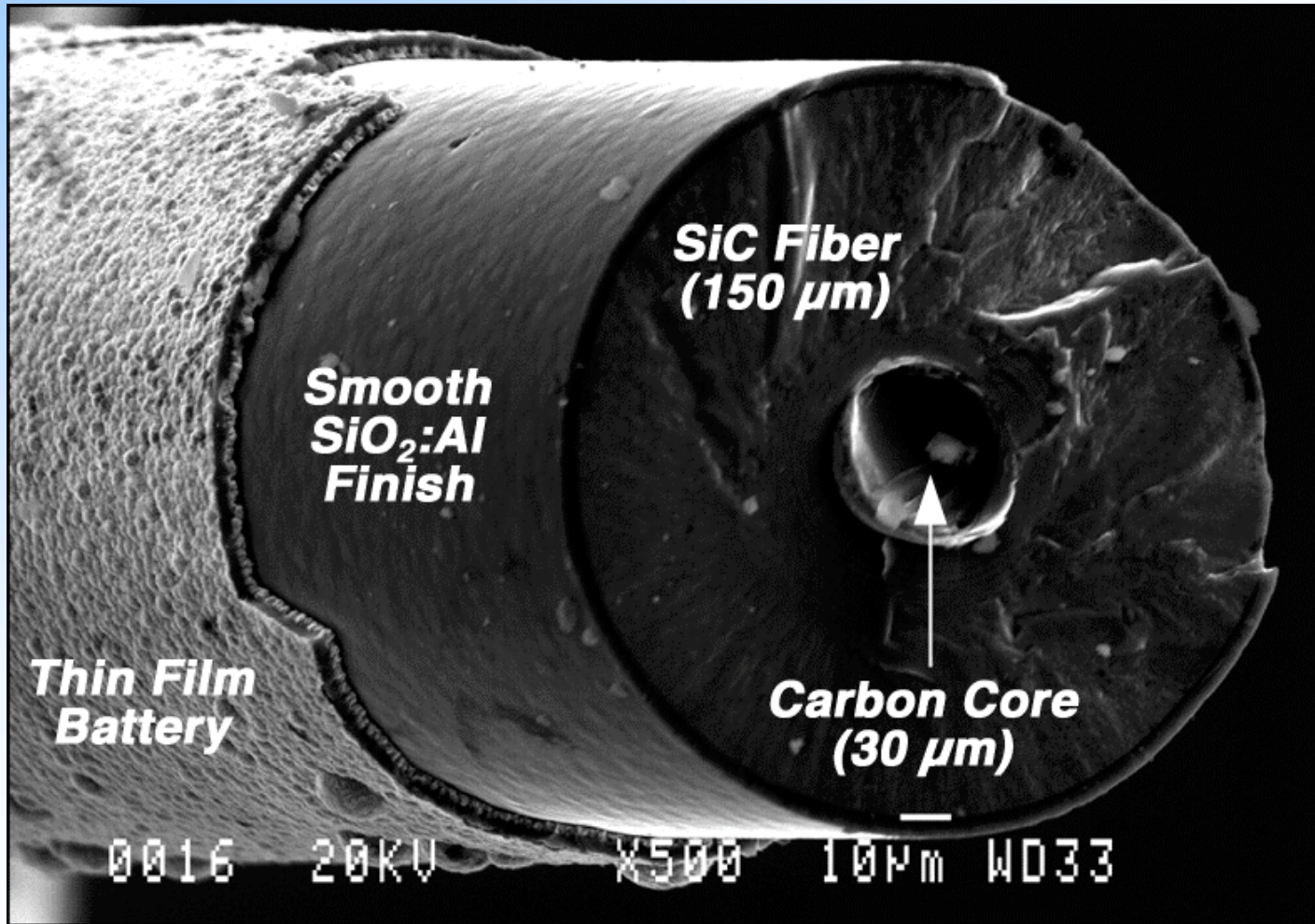
## ■ *First PowerFiber (February 2001)*

- 150  $\mu\text{m}$  Diameter Sapphire Fiber
- Lithium-Free Battery Configuration
- 1.3  $\mu\text{m}$  a-Li<sub>1.6</sub>Mn<sub>1.8</sub>O<sub>4</sub> Cathode (Li source)

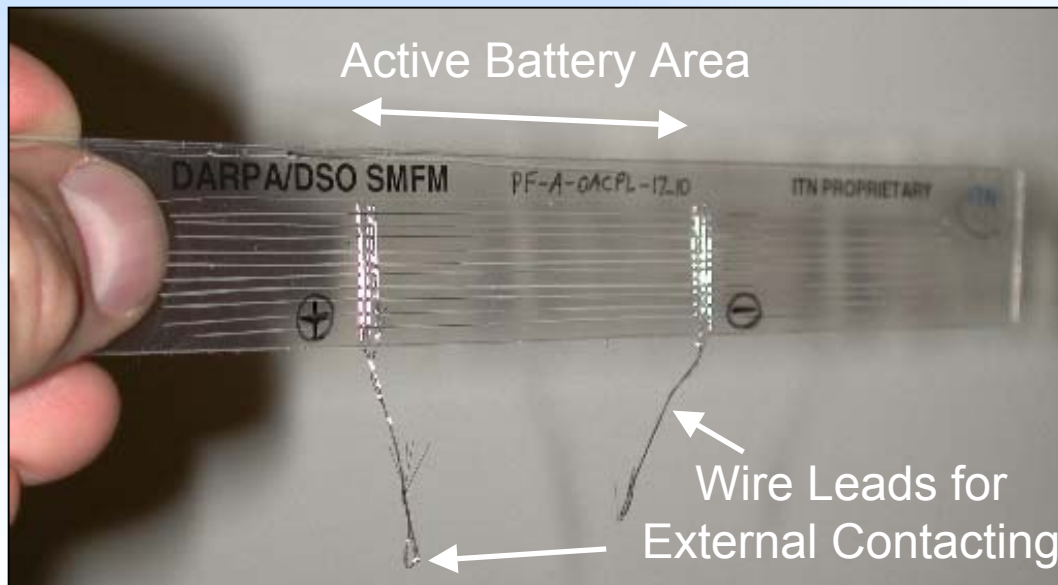
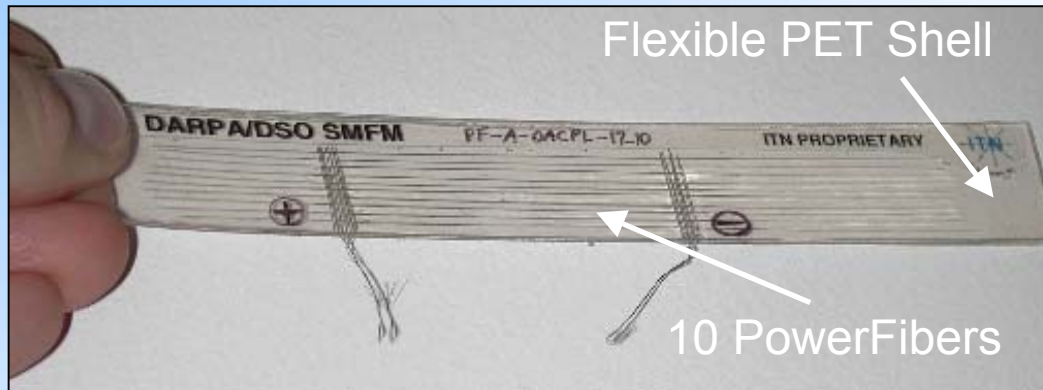




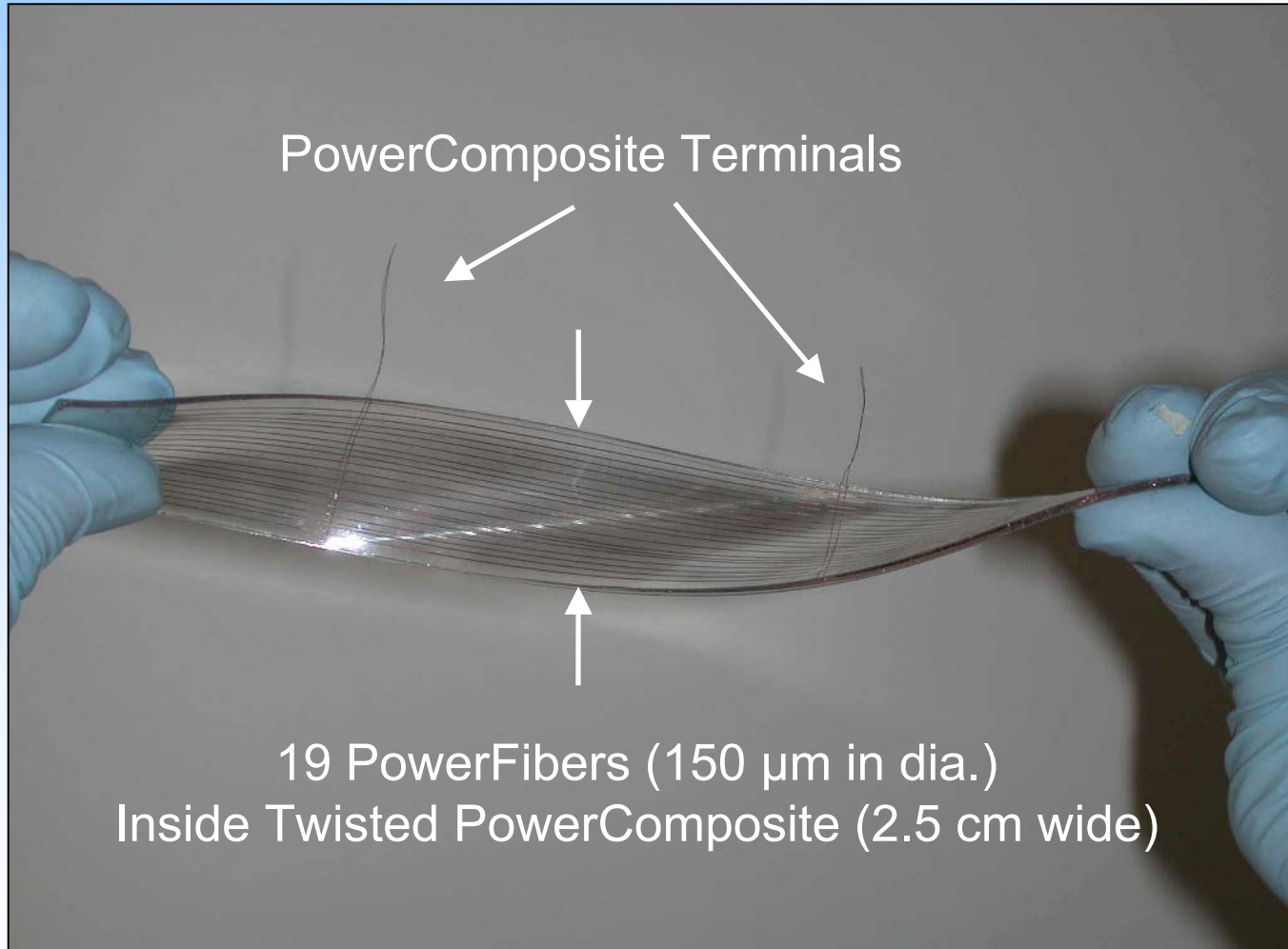
# SEM Micrograph of "Buried Li-Free" PowerFiber on SiC Fiber



# PowerComposite with 10 PowerFibers inside PET Matrix



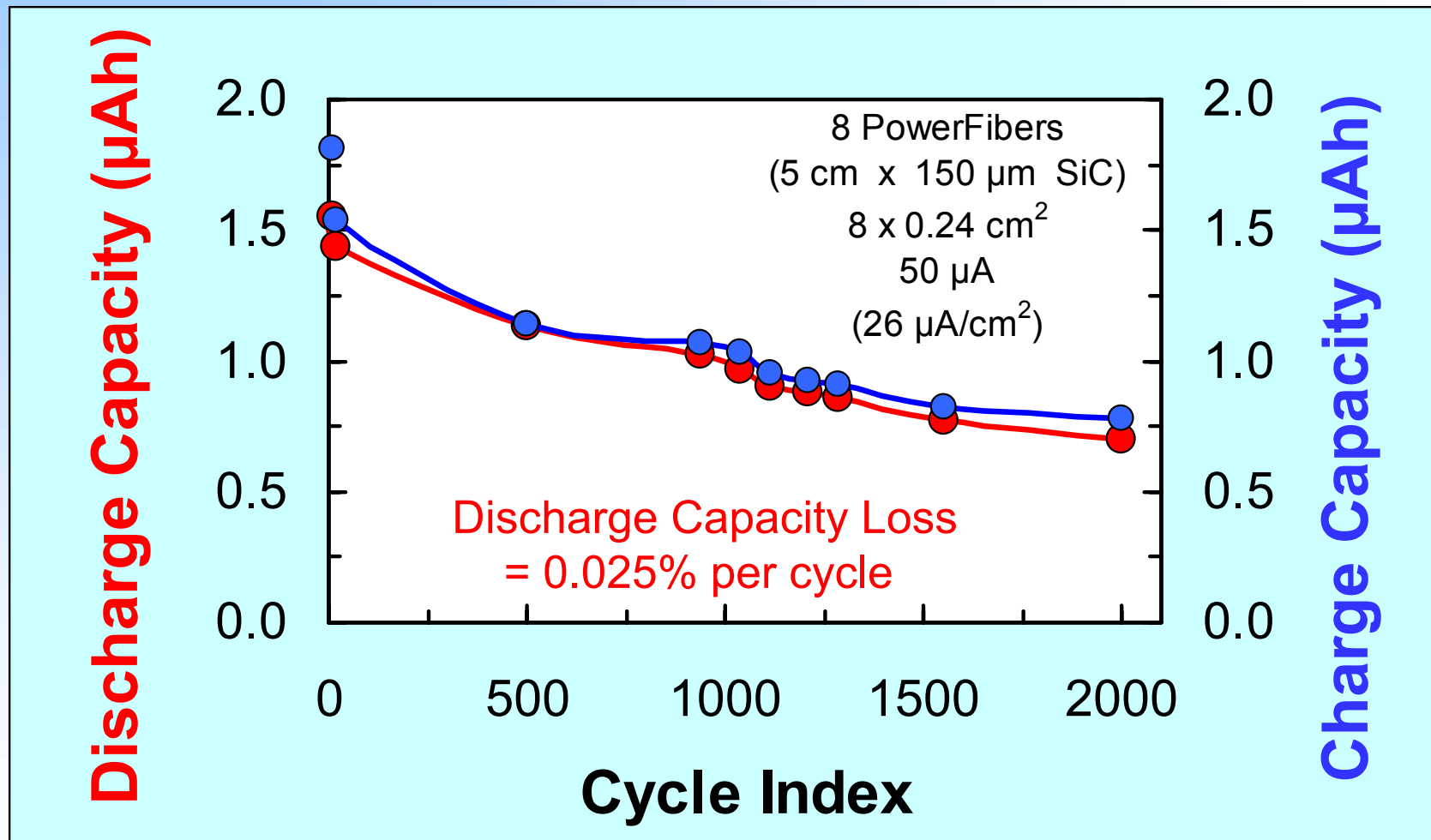
# PowerComposite: Electrochemical Testing under Deformation



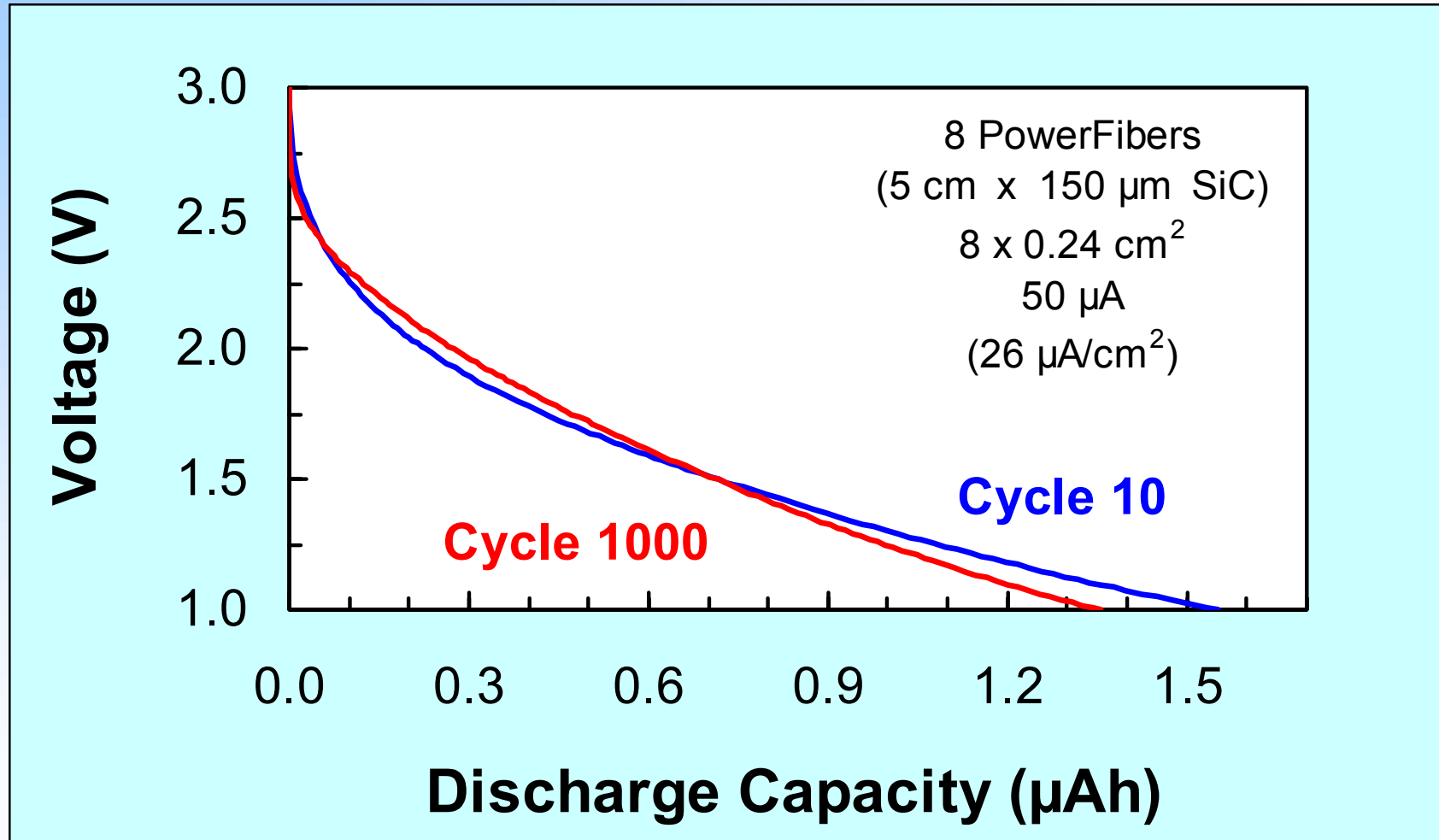
PowerComposite Terminals

19 PowerFibers (150  $\mu\text{m}$  in dia.)  
Inside Twisted PowerComposite (2.5 cm wide)

# PowerComposite ("Buried Li-Free" with $\text{Li}_2\text{V}_2\text{O}_5$ Cathodes)



# PowerComposite ("Buried Li-Free" with $\text{Li}_2\text{V}_2\text{O}_5$ Cathodes)

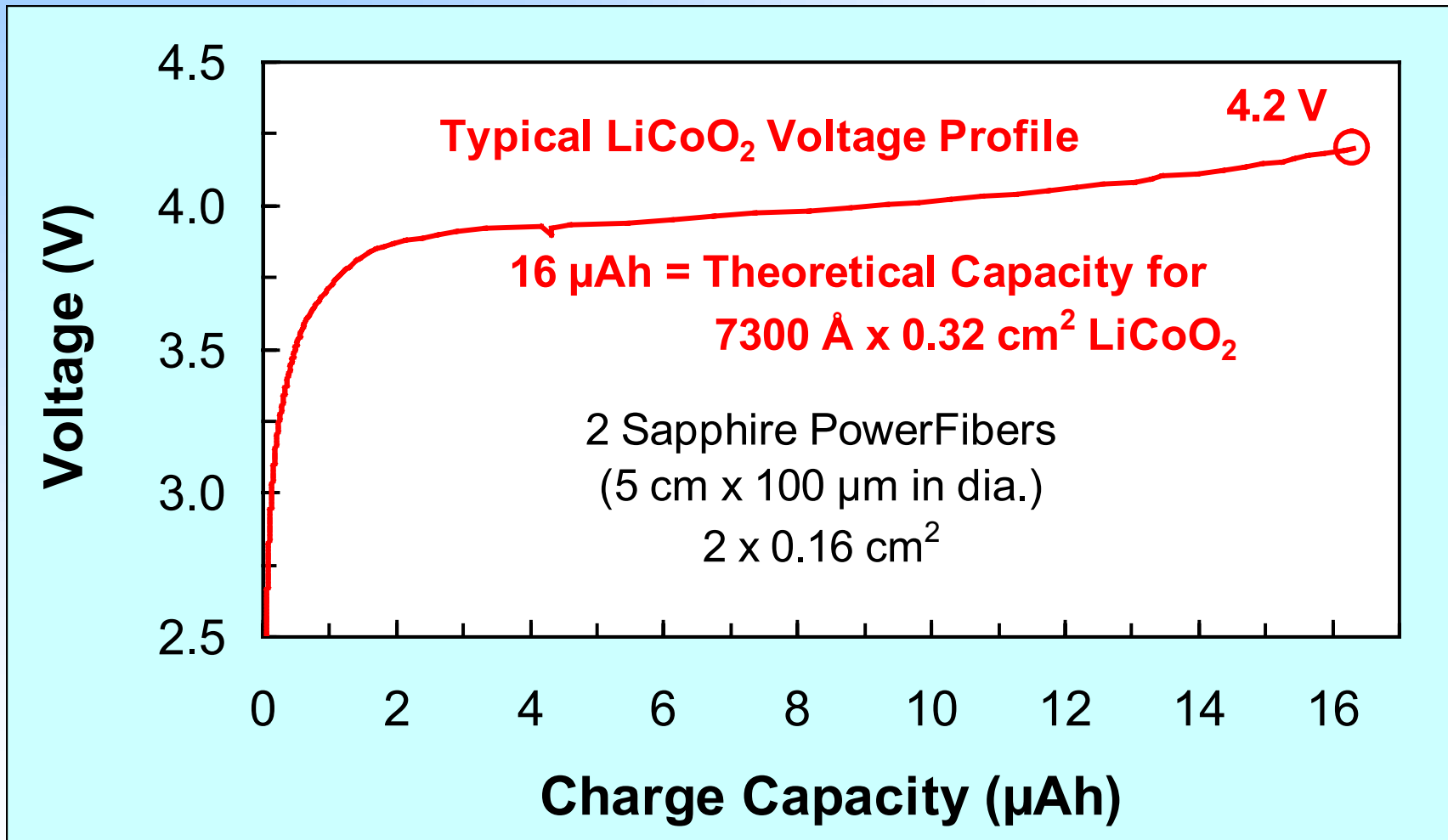


# PowerFiber Cathodes

- ***Cathodes (+) Determine Energy and Power !***  
**Also: Voltage, Power, Weight, and Volume**

Year	Cathode Material	Relative Discharge Energy @ > 1 mA/cm <sup>2</sup>
2001	amorphous $\text{Li}_{1.6}\text{Mn}_{1.8}\text{O}_4$	1
2002	amorphous & crystalline $\text{Li}_x\text{V}_2\text{O}_5$	10
2002	<b>crystalline <math>\text{LiCoO}_2</math></b>	<b>&gt; 100</b>

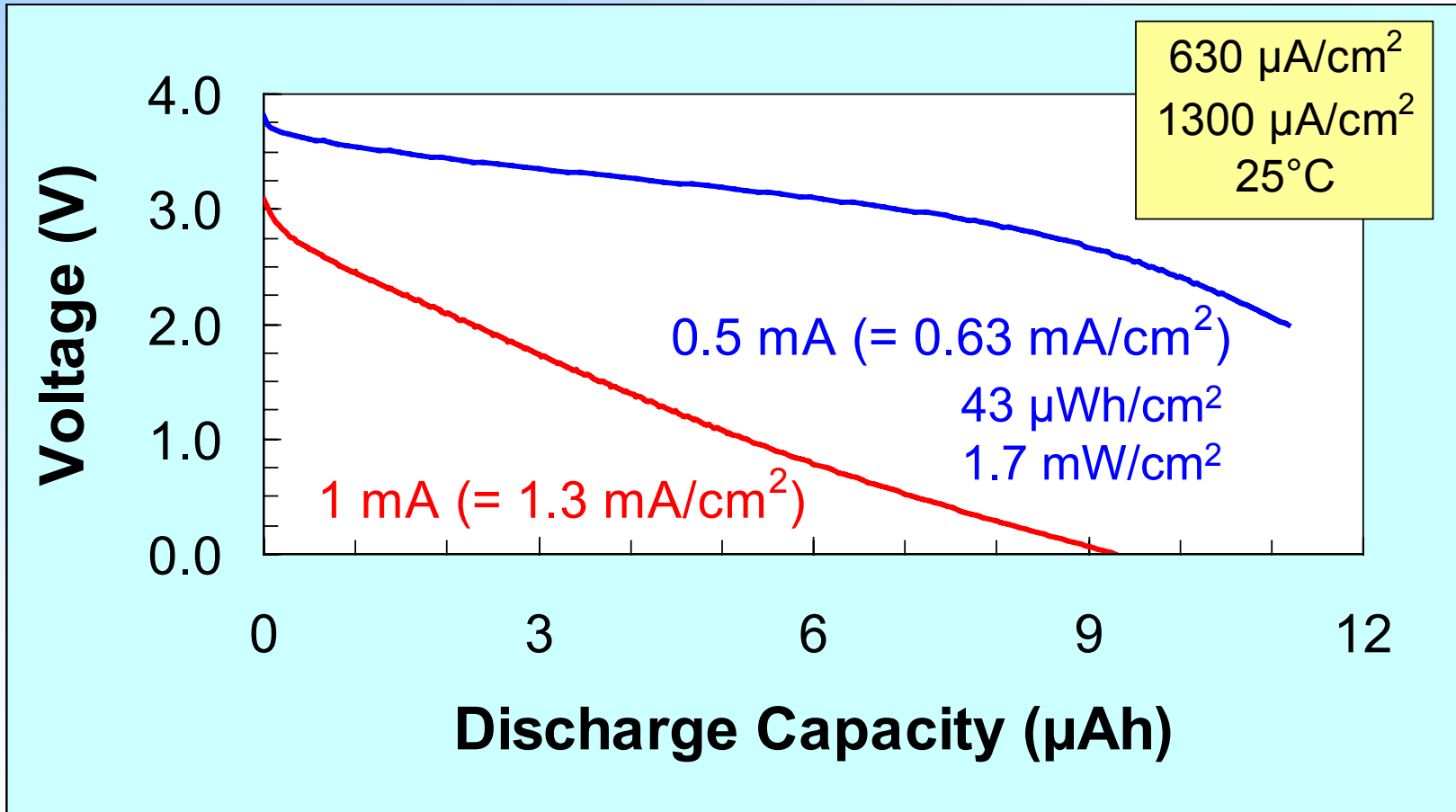
# PowerComposite: "Li-Free" and $\text{LiCoO}_2$ Cathodes



# PowerFiber Rate Capability: "Li-Free" and $\text{LiCoO}_2$ Cathodes



- 1 mWh and 39 mW per 7m (23 feet) PowerFiber ( $\text{Ø}100 \mu\text{m}$ )





# PowerFiber Technology

## Summary – Conclusions – Outlook



### ■ *ITN's Thin-Film Batteries @ 100% DOD*

- ❑ >2,000 demonstrated for PowerFibers (with challenging “Li-free” !)
- ❑ >90,000 demonstrated for flat configuration (38% overall capacity loss)
- ❑ Battery operation demonstrated between – 45°C to +120°C
- ❑ Battery life-time commensurate with device life-time

### ■ *Very Safe Inorganic Battery Technology*

- ❑ No fuming, no outgassing, no burning, no explosion, no thermal runaway
- ❑ Only limited local heat generation in case of accident
  - ] Small battery mass per unit length of fiber
- ❑ Controlled heat dissipation in PowerFiber network
  - ] Vastly spread-out heat sink

### ■ *Payoffs for Space and Aviation Applications*

- ❑ Spacecraft structure itself becomes a battery (increases payload)
- ❑ Distributed power storage (power structure is “everywhere” in space bus)



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