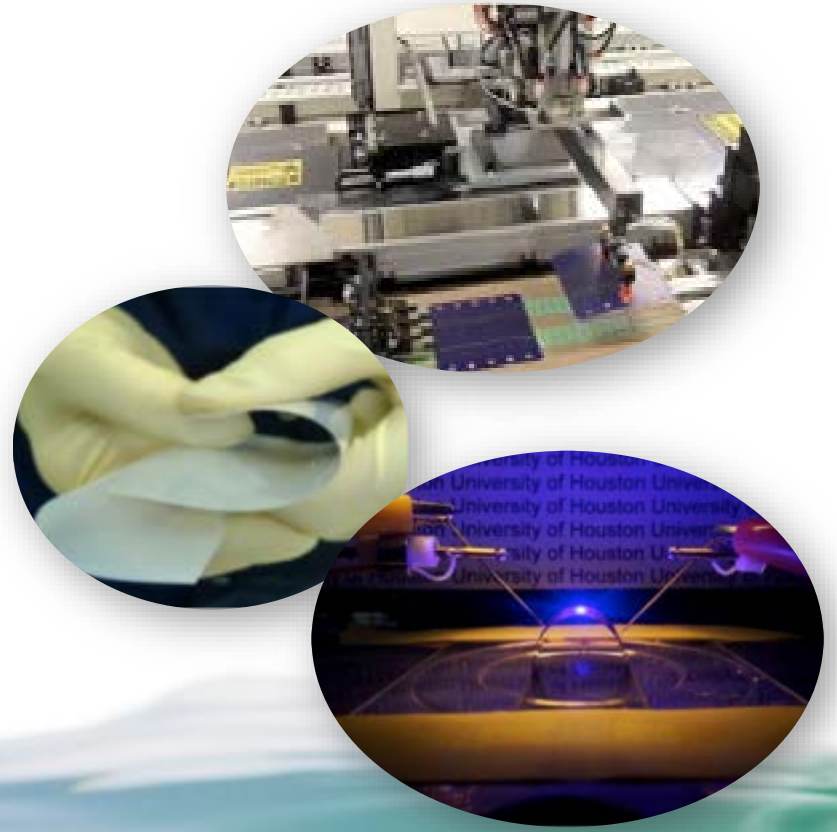
Zirconia Ribbon Ceramic

ENrG Incorporated
John A. Olenick
President & CEO



3/25/2018

About ENrG

- Located in Buffalo, NY.
- UltraThin Flexible Ceramic.
- Produce for the Energy, Electronics, and Medical markets.
- Technology is licensed from Corning.
- Supported by NYSERDA and FlexTech Alliance and grant funding.
- In 2015, implemented strategy to move from sheet to R2R processing.

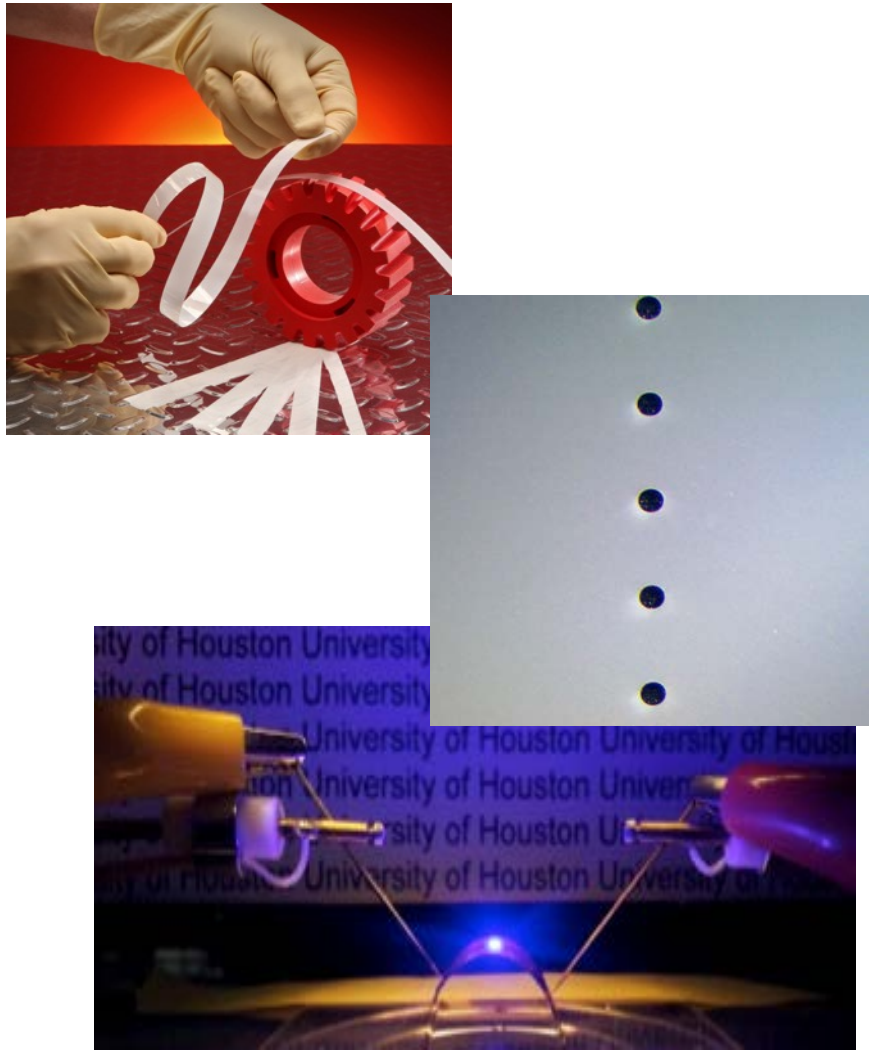
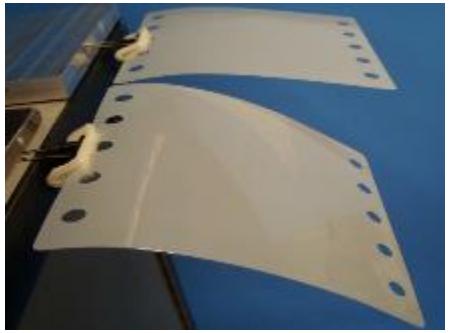


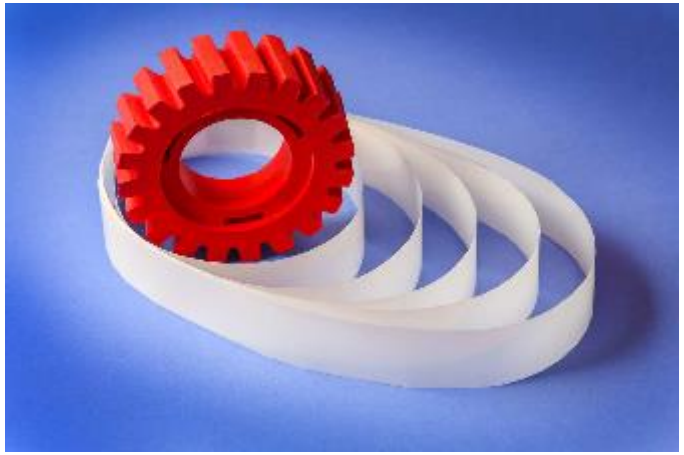
Photo courtesy of University of Houston

UltraThin Flexible Ceramic

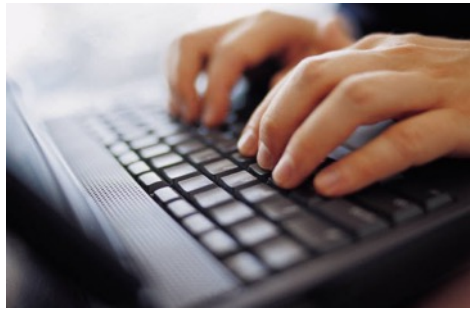
Thin E-Strate®

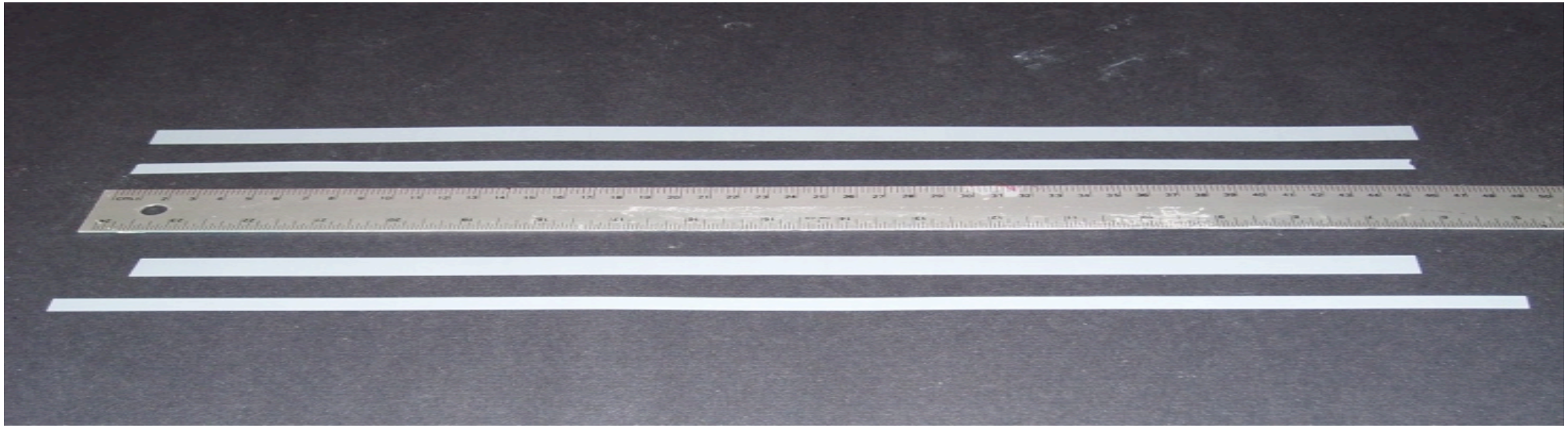
- Ultra-thin, dense, 3 mol% YSZ (3YSZ)
- Available 20, 40µm
- Demo 12u, 7u in production laboratory
- Tooled for various sheet sizes, largest is 12x15 cm
- 2017 Ribbon Ceramic is 10-32mm wide by 30 meters





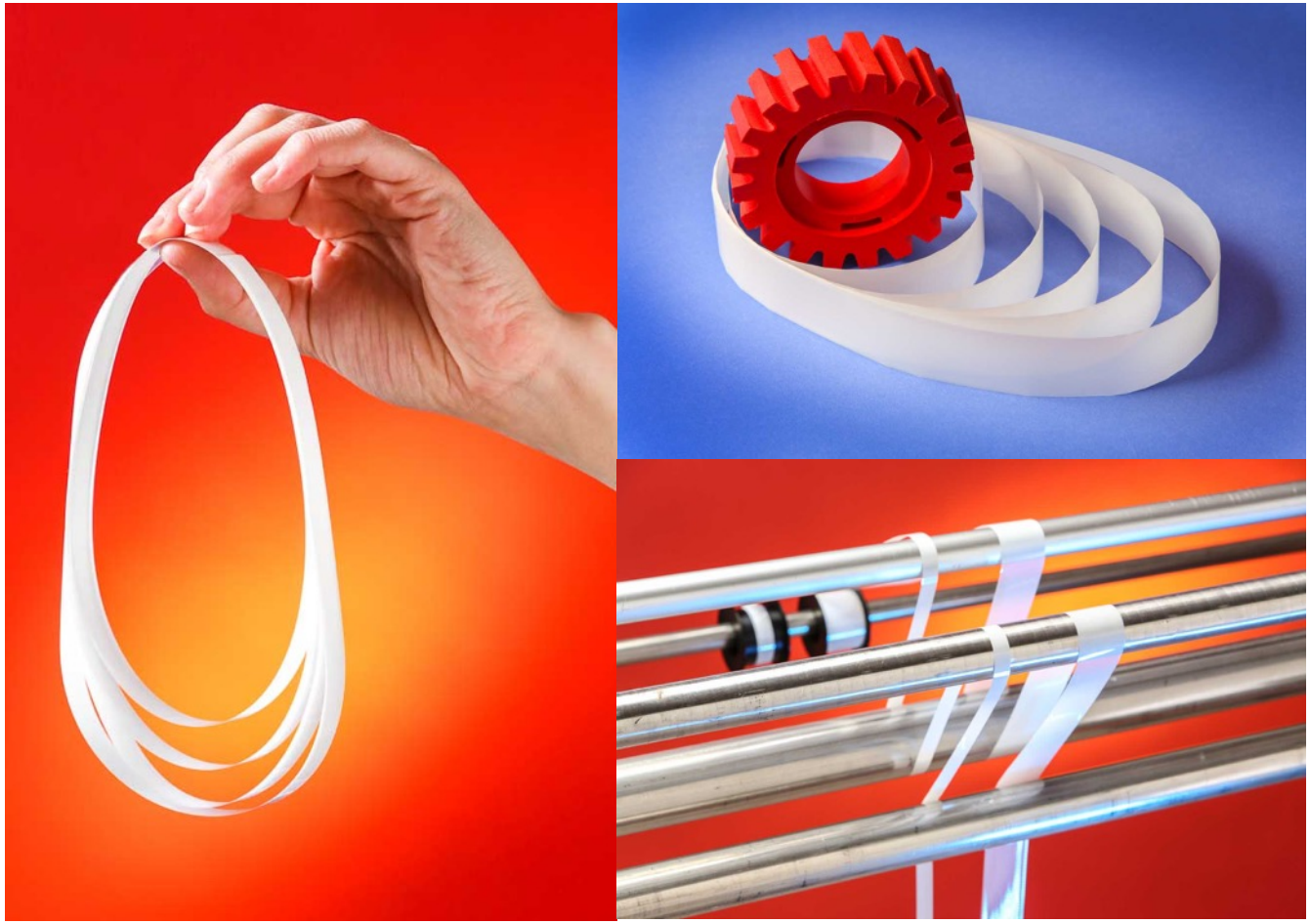
Ribbon Ceramic - Never Been Done…….



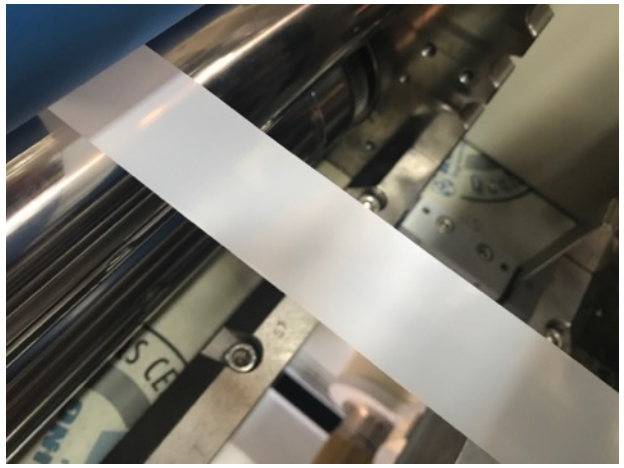


Zirconia Ribbon Ceramic = Thin E-Strate® + R2R

- Why R2R Ceramic?
  - Market demand
  - Better quality product
  - Less energy
  - Higher productivity
  - Able to R2R coat
- Gen 2
  - 20-40µm Zirconia Ribbon Ceramic (ZRC)
  - Widths 10-60 mm, intro 100mm
  - Length: 10-100 meters
- Continued relationship with Corning for R2R format & other materials.

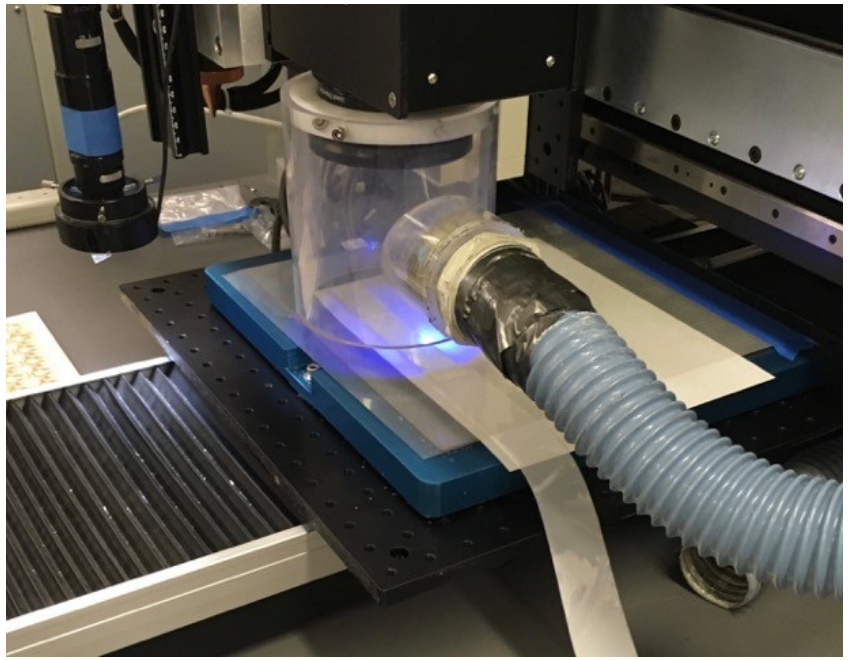


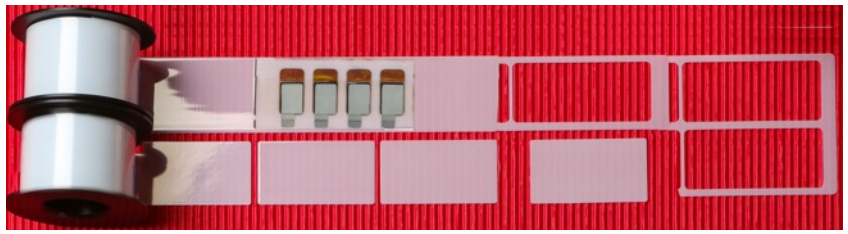
Coatings: DCS, R2R Format, Intellivation

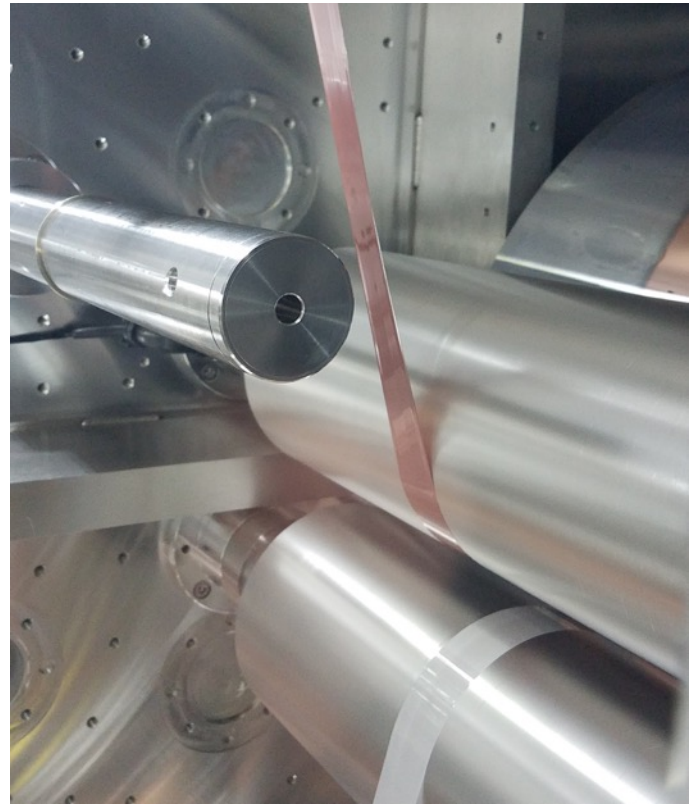


Demonstration of R2R Lamination of OCA onto Zirconia Ribbon Ceramic

Photo & demo courtesy of Dorey Converting Systems



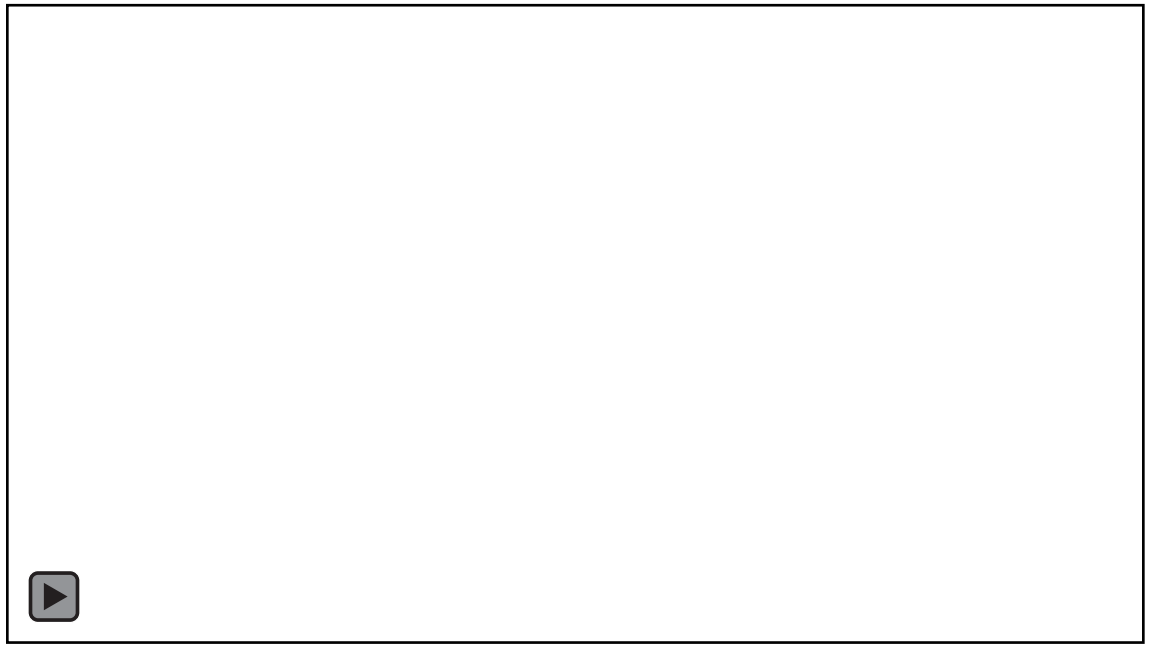




R2R Vacuum Sputtering of Copper onto 20µm thick Zirconia Ribbon Ceramic

Photo & demo courtesy of Intellivation

Coating: R2R Deposition of Functional Thin Films on ZRC



Zirconia Ribbon Ceramic *moving in R2R deposition tool*

Development of single-crystalline-like III-V GaAs, Si and Ge films with **high carrier mobilities** on ceramic tapes

R2R Ion-beam assisted deposition (**IBAD**) process used to achieve single-crystal-like highly textured films on amorphous ceramic tapes

High mobility → High performance devices

Several R2R plasma-assisted chemical vapor deposition (CVD), sputter, e-beam tools are available at **Univ. of Houston**

Applications targeted include flexible energy devices (PV, LED), electronics, sensors, RF devices, etc.

Advanced Manufacturing Institute (AMI)
University of Houston

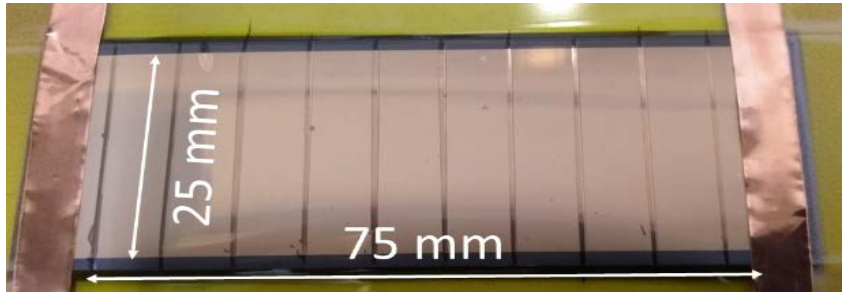
Team Members: Pavel Dutta, Ying Gao, Sicong Sun, Monika Rathi, Venkat Selvamanickam

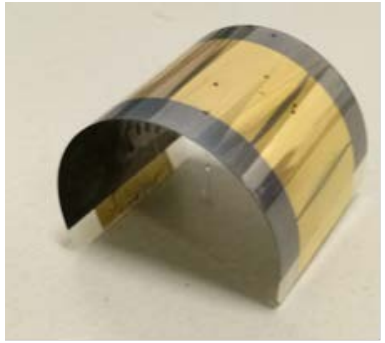
Surface Energy of Thin E-Strate® is 53.96 (dyne/cm), having 30.96 dispersive and 23.01 polar components, respectively*

Data courtesy of *Michael Joyce, PhD Student, Chemical & Paper Engineering, College of Engineering & Applied Sciences, Western Michigan University

Energy Harvesting – Solar PV

- Superstrate CdTe
- Translucent thin YSZ serves as both the superstrate and hermetic cover sheet
- No out-diffusion from the thin zirconia
- Dimensional stability under temperature cycling is excellent
- Integrating with Solid State Thin Film Battery to create a Flexible Integrated Power Pack (FIPP)
  - Team: ITN Energy Systems, Lucintech, ENrG Inc., FlexTech





ITN ENERGY SYSTEMS

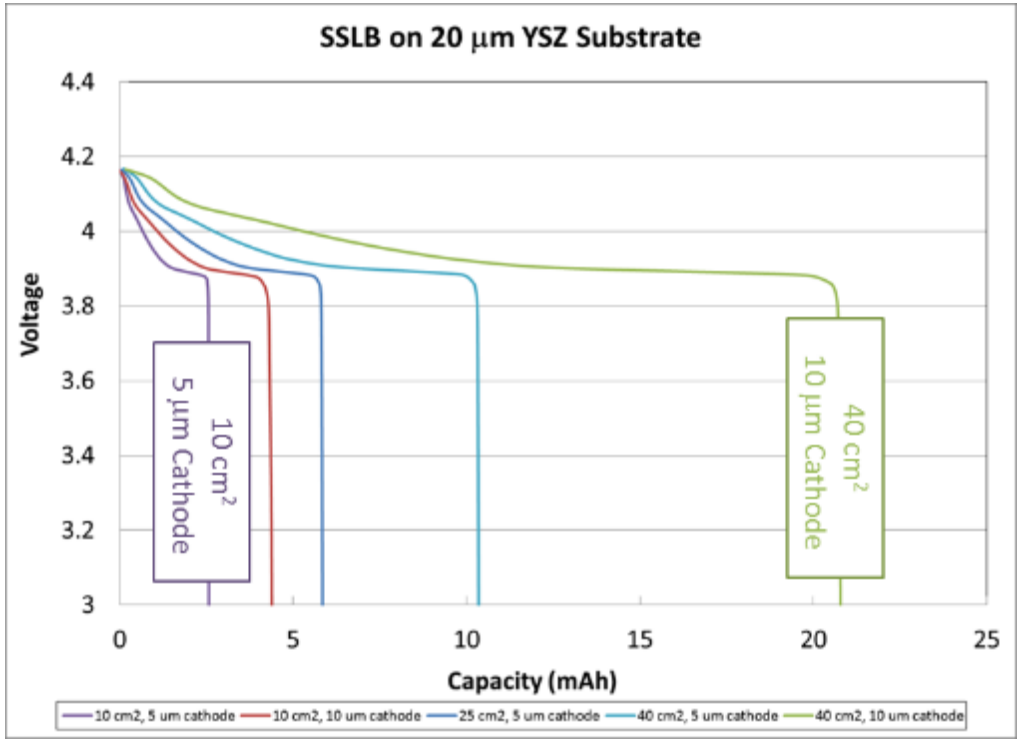
Lucintech TRANSPARENT POWER

ENrG Inc.

SSLB on Flexible Ceramic Substrate

- ITN Has Produced SSLB on ENrG Flexible Ceramic Substrates
  - As Thin as 20 μm YSZ
  - Area Up to 40 cm^2
  - Cathodes up to 15 μm Thick

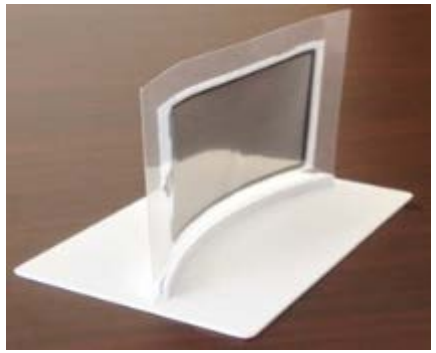
- Ultra-Thin, Flexible High Energy Density SSLB Possible with This Approach
  - Up to 600 Wh/l
  - 1-150 mAh Capacity
  - Package Thickness < 250 μm

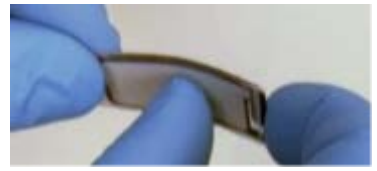


40 cm^2 SSLB

R2R Enables Higher Energy Density SSLB Opportunities

- Unprecedented Energy Density >1,000 Wh/l
- Enables High Volume, Low Cost Manufacturing
- Full Integration - the Device is the Package
  - “Kicks the Can”
- Novel Flexible, Ultrathin Batteries for Wearables, Medical, Flexible Electronics
- Safe Alternative to Lithium Ion Batteries





Ultrathin Ceramic Ribbon (<20 μm Thick)

Substrate & Packaging: Flip Chip LEDs on Thin E-Strate®

Low Thermal Resistance Enables LED Longer Life & Efficiency

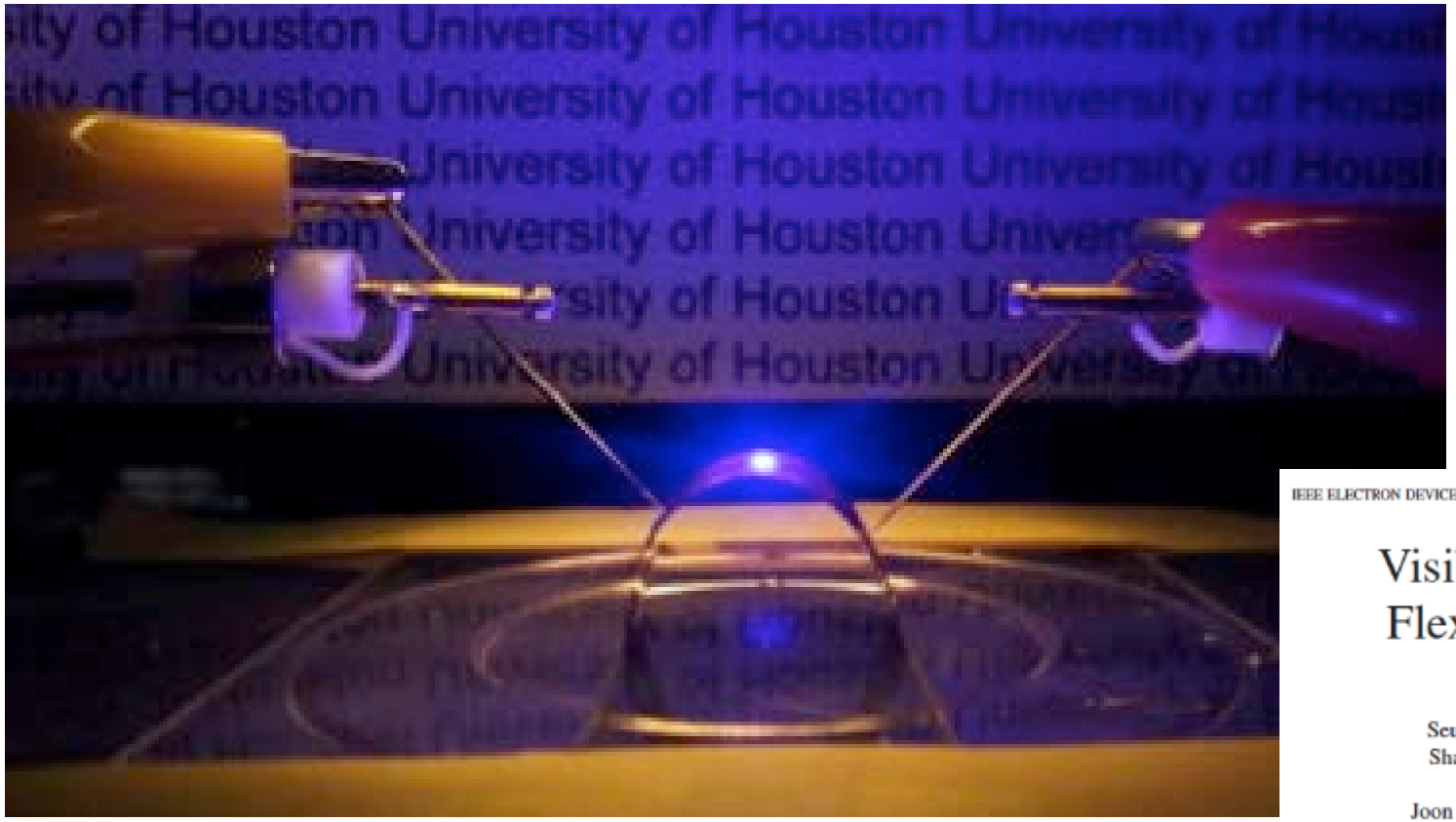


Photo courtesy University of Houston

LED surface Temp at 10 mA:

9°C cooler on Thin E-Strate® over polyimide

IEEE ELECTRON DEVICE LETTERS, VOL. 37, NO. 5, MAY 2016

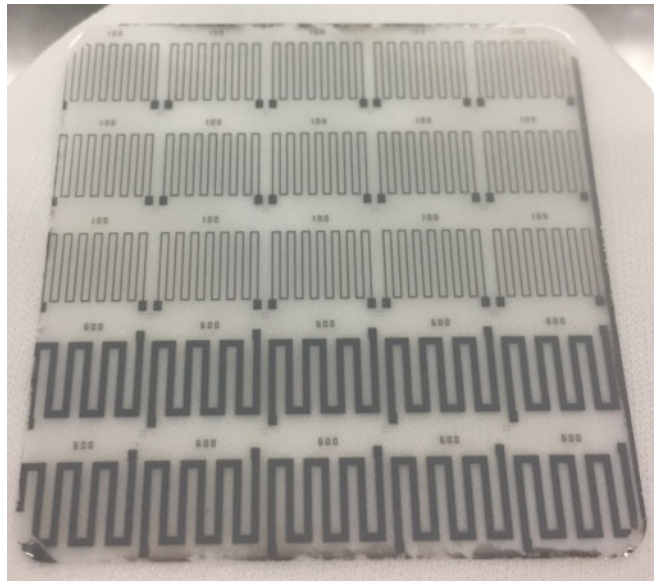
Visible Flip-Chip Light-Emitting Diodes on Flexible Ceramic Substrate With Improved Thermal Management

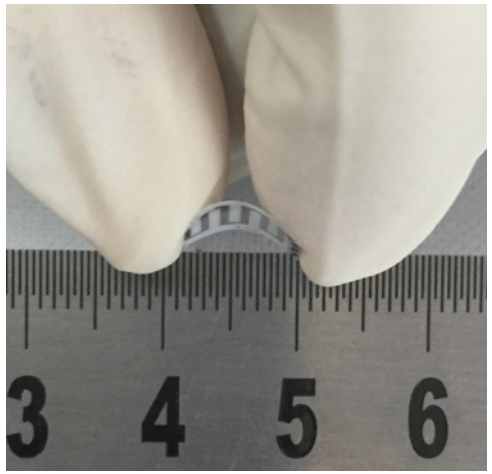
Seung Hwan Kim, Shivkant Singh, Seung Kyu Oh, Dong Kyu Lee, Keon Hwa Lee, Shahab Shervin, *Student Member, IEEE*, Mojtaba Asadirad, *Student Member, IEEE*, Venkat Venkateswaran, Kathy Olenick, John A. Olenick, Sung-Nam Lee, Joon Seop Kwak, Anastassios Mavrokefalos, and Jae-Hyun Ryou, *Senior Member, IEEE*

http://www.mdpi.com/212662:
Flexible Mixed-Potential-Type (MPT) NO2 Sensor Based on An Ultra-Thin Ceramic Film

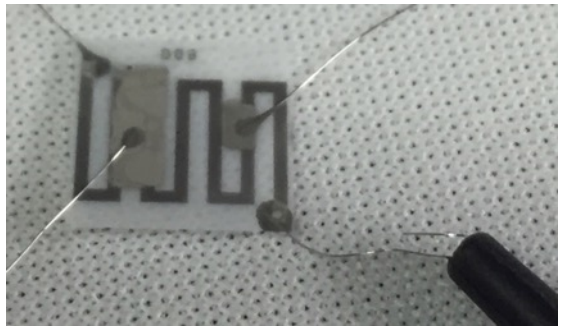
Gas Sensing: NO_x Sensors

- Structure: heating electrode – 20μm thick YSZ - reference/sensing electrodes
- Excellent performance to detect NO_2
  - Sensitivity achieved: 58.4 mV/decade at 200°C
- Superior mechanical stability after bending over 50 times
- Fast response time <10s at 200 ppm
- Low power (1025 mW) at 200°C, 8.0 mm x 6.4 mm area





清华大学 Tsinghua University 精密仪器系 Department of Precision Instrument



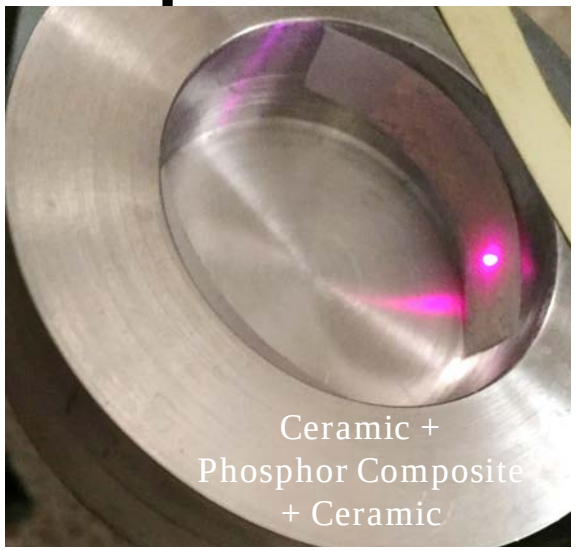
Flexible Mixed-Potential-Type (MPT) NO_2 Sensor Based on An Ultra-Thin Ceramic Film

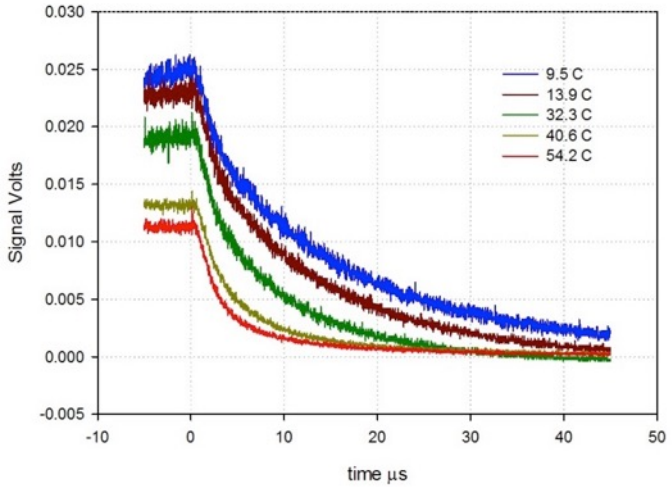
Rui You [1,2], Gaoshan Jing [1,2,*], Hongyan Yu [1,2] and Tianhong Cui [3,*]

Non-destructive, In-Situ High Temperature Sensing: Phosphors

- ***Phosphor thermometry***: Emission of light from a compound after being remotely excited. Properties of the emitted light contain temperature information. "Decay time" corresponds to time taken for emitted signal to drop in intensity. How quickly it drops signifies the temperature.

- Remote Thermometry applications
  - Optoelectronics, Aerospace, Insulation
- Advantages:
  - Detachable, Re-useable, Flexible
  - Broad temperature range: Cryogenics to 1000°C
  - Lightweight, Inert, Chemically stable
  - Controlling doping / coating concentration can control sensitivity and intensity
  - Remote sensing, low power, instantaneous, wireless, accuracy < 1°C



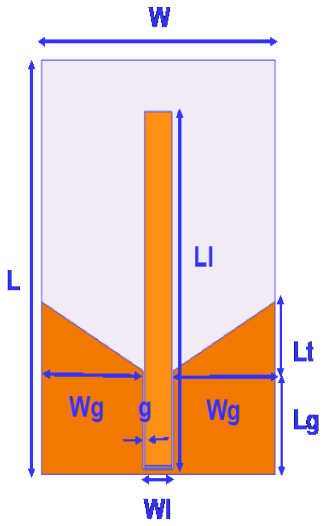


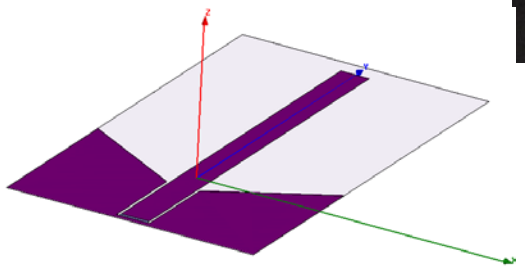
Dr. Firouzeh Sabri, Laboratory of Bio, Nano, and Space Materials, Department of Physics and Materials Science

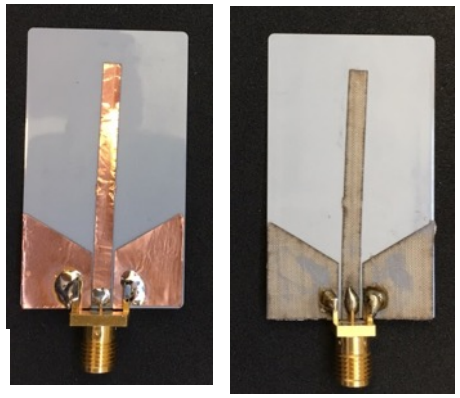
Antennas

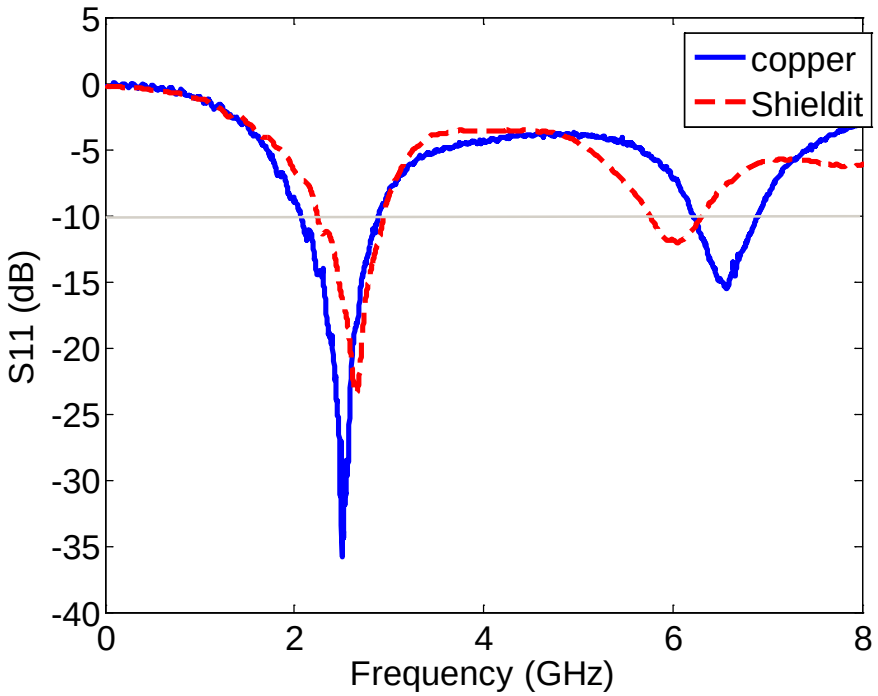
- Coplanar Waveguide (CPW)-fed Monopole antenna on ENrG's Thin E-Strate®

Copper vs Electrotextile (Shieldit) as conductor layers





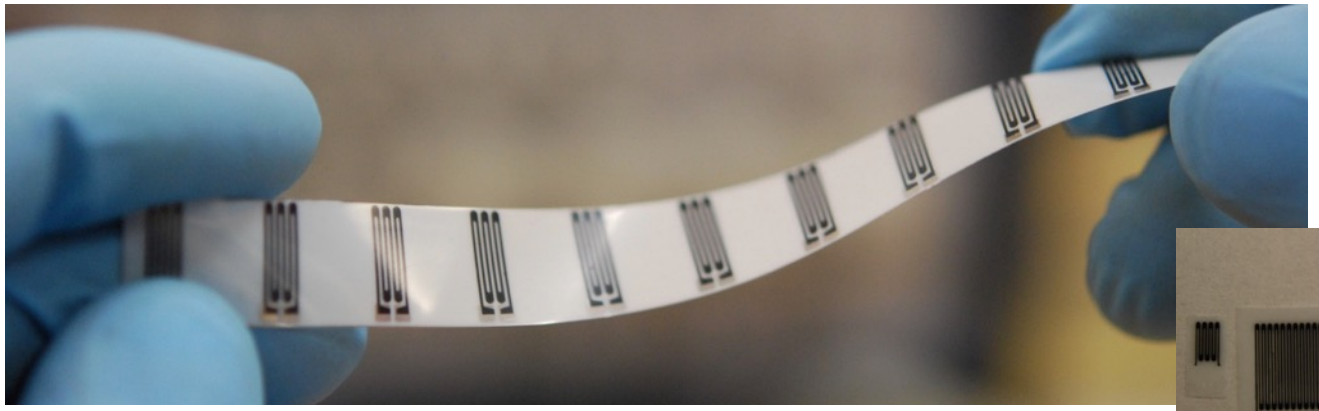


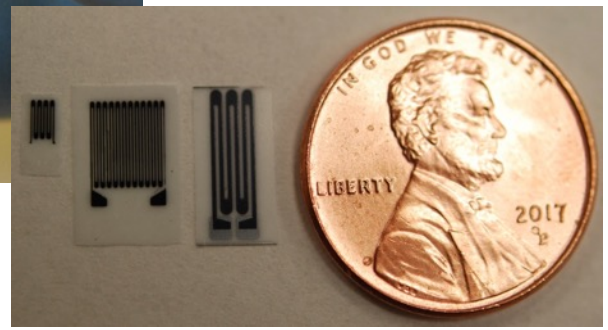


Dr María Elena de Cos, Associate Professor, TSC-UNIOVI, Electrical Engineering Department, University of Oviedo, Spain

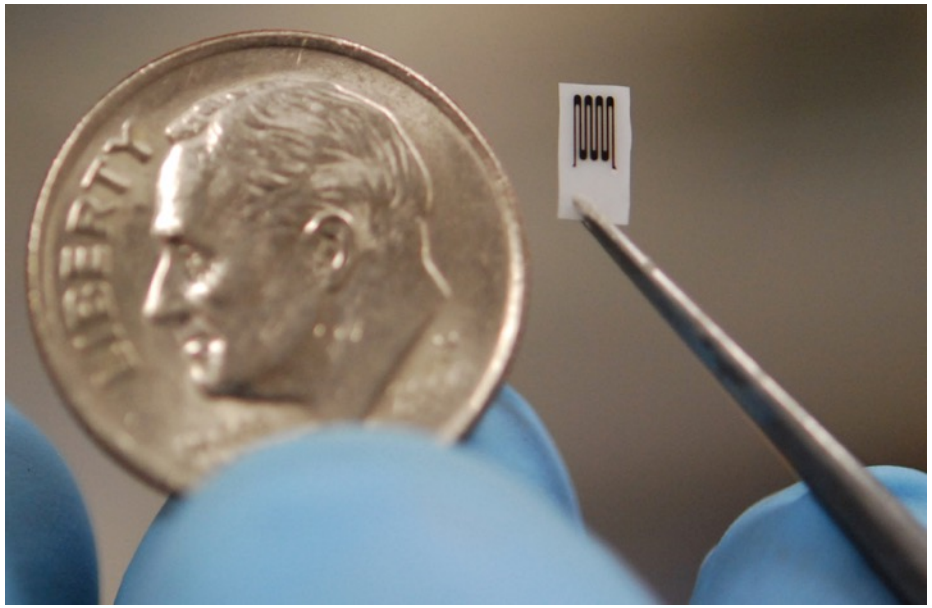
Both prototypes properly matched at main resonance frequency, however the copper one seems to exhibit better performance

Strain Gages





- ITO strain gauges patterned on 20 μm thick 3YSZ ceramic

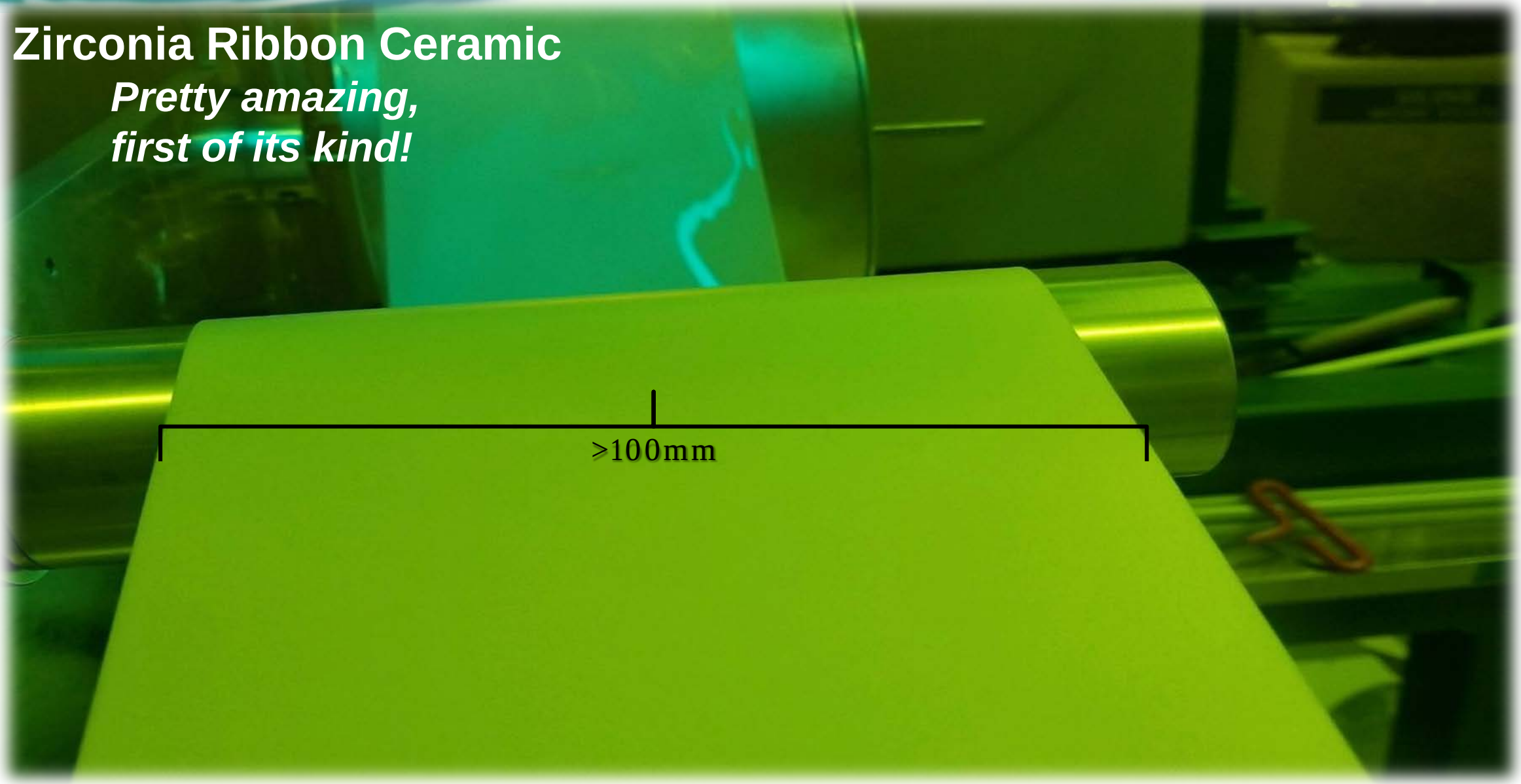


Matthew Ricci
Chemical Engineering Graduate Research Asst. University of Rhode Island | Kingston, RI

THE UNIVERSITY OF RHODE ISLAND

Zirconia Ribbon Ceramic

Pretty amazing,
first of its kind!



Acknowledgements to:

FlexTech Alliance; Dr. Michael Badding, Corning's Ceramic and Automation Groups; Dr. Brian Berland, ITN Energy; and NYSERDA.

Thank You for Attending!

Questions?