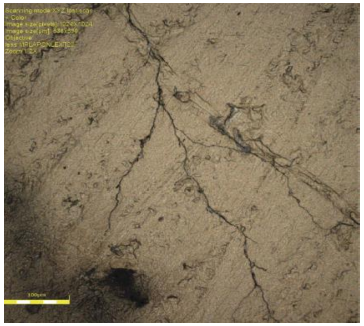
Self-healable Electrical Insulation for High Voltage Applications

Tiffany S. Williams, Ph.D.
Materials and Structures Division
NASA Glenn Research Center
Cleveland, OH, USA

The need for self-healing insulation

- **<u>State-of-the-Art Insulation</u>:** Polyimide-based **(High Temperature Insulation)**
  - **Advantages**
    - Good dielectric properties
    - High thermal stability
  - **Disadvantages**
    - Moisture absorbance → Electrical fires

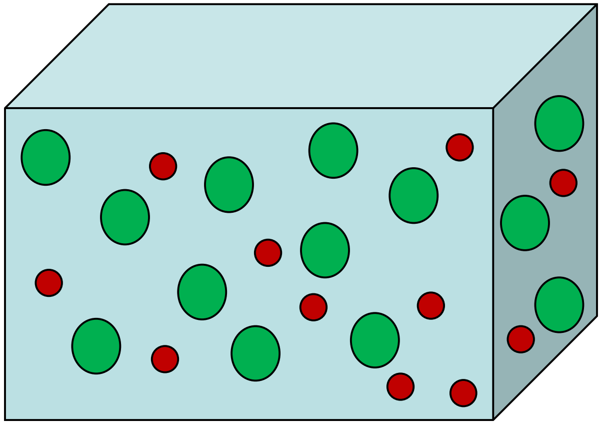


Electrical Treeing

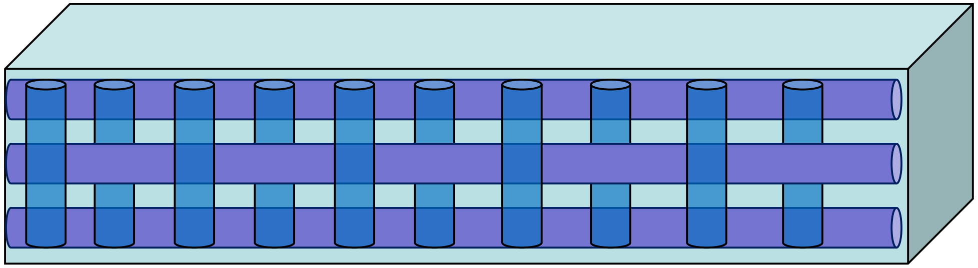
- **<u>Problem</u>:** Polymeric aircraft electrical insulation are highly prone to damage by
  - Corona at altitude causes breakdown of air pockets & small gaps (electrical treeing→ onset dielectric failure)
  - Abrasion and cuts (maintenance)
  - Damage to electrical insulation leads to electrical shortage and/or fires
- **<u>Objective</u>:** To increase aircraft safety and longevity of electrical insulation over state-of-the-art insulation through self-healing
  - ➢ **Reduced repair costs and maintenance**

"Self-Healing" Materials

Extrinsic Healing

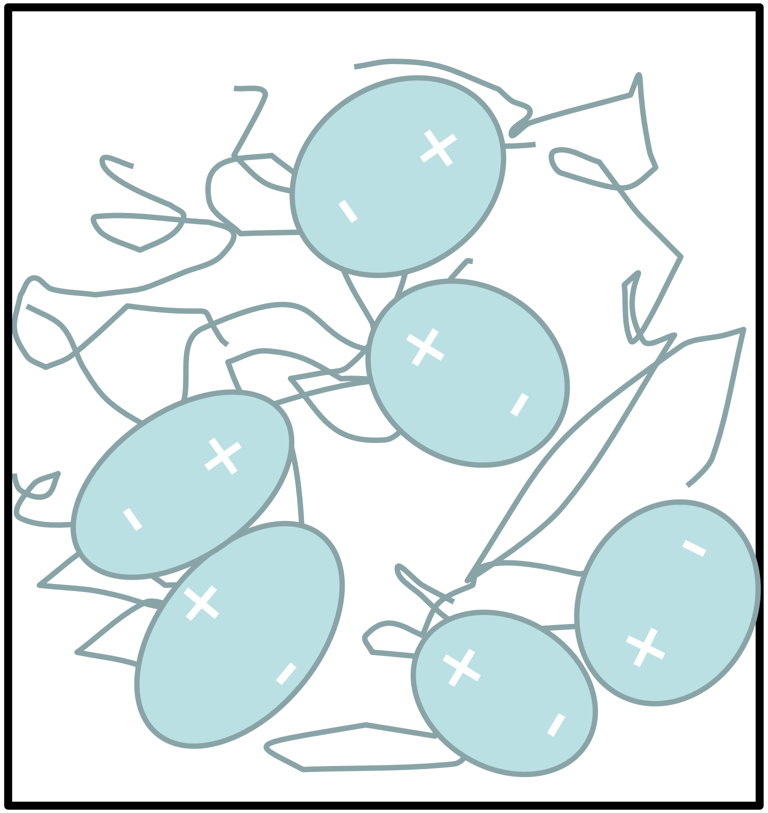


Embedded microcapsules filled with healing agents that flow and polymerize when cracks are formed.



Microvascular networks filled with healing agents that flow and polymerize when cracks are formed.

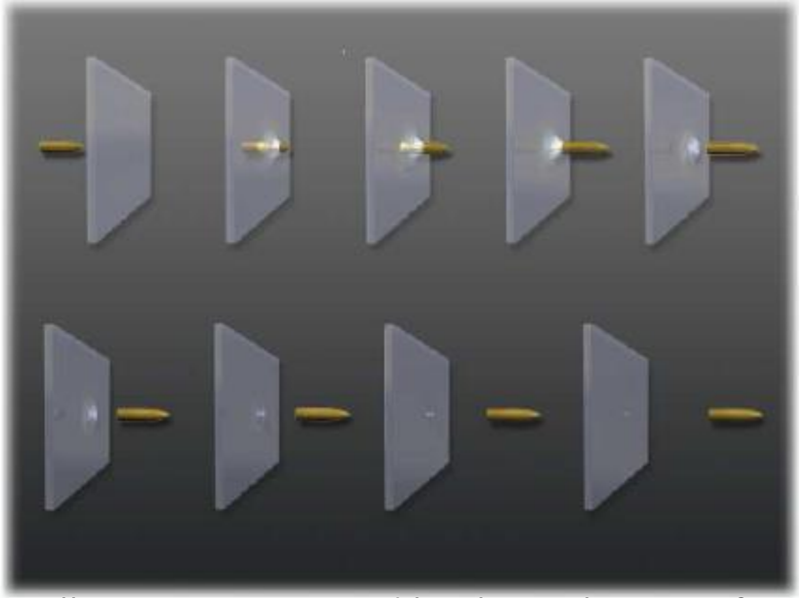
Intrinsic "Reversible" Healing



Ionic clusters and other bonds that can break and re-aggregate

Surlyn ®

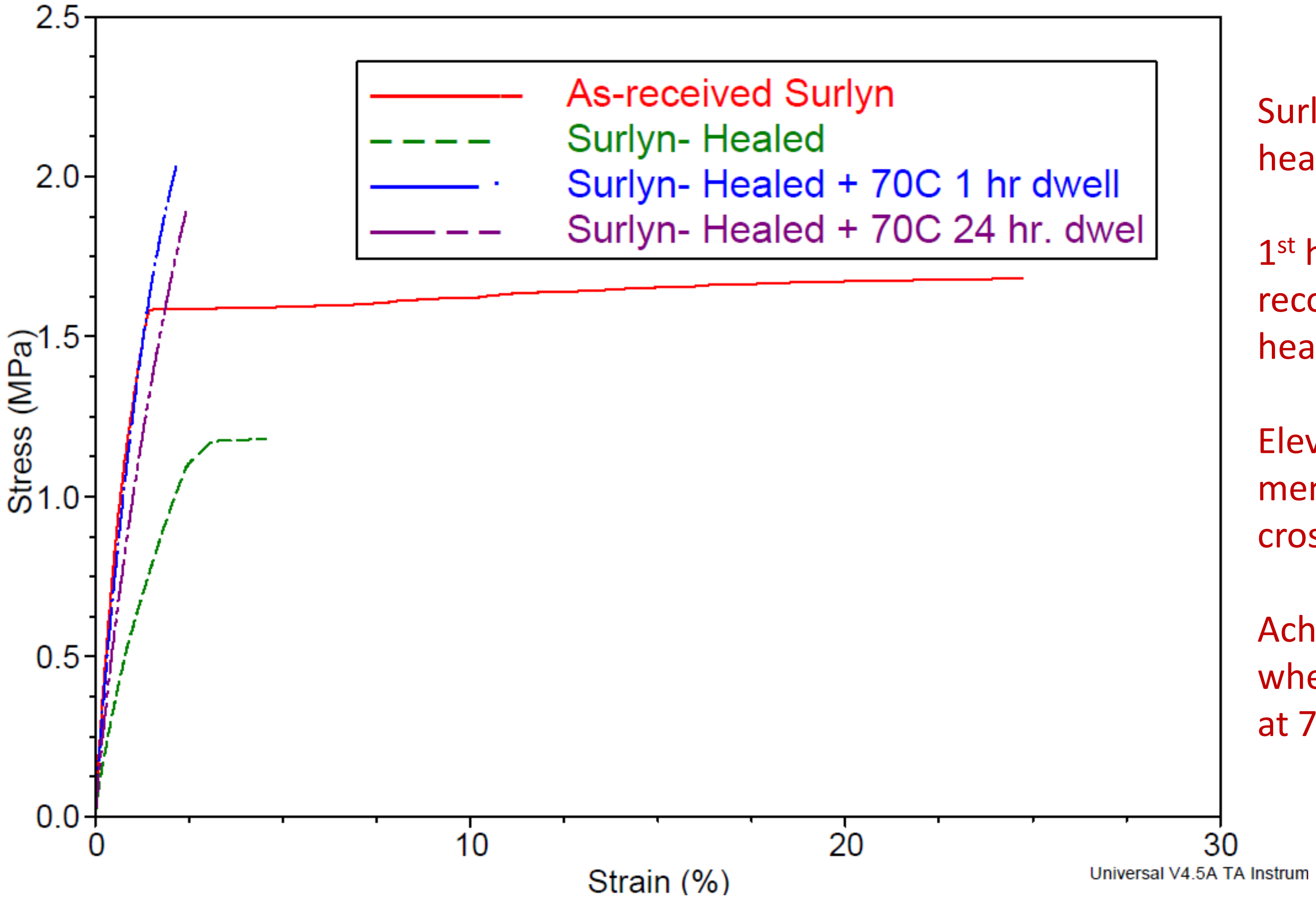
- Ethylene methacrylic acid copolymer
- Commonly used as packaging materials – puncture resistance
- Previously investigated for impact-related healing
- Ionic crosslinks thermally reversible
- Thermal energy upon from impact believed to be high enough to initiate self-healing



Bullet penetration and healing schematic for intrinsically healable materials

[K. Gordon et. al, Puncture Self-healing Polymers for Aerospace Applications, NASA Langley]

Self-healing Potential



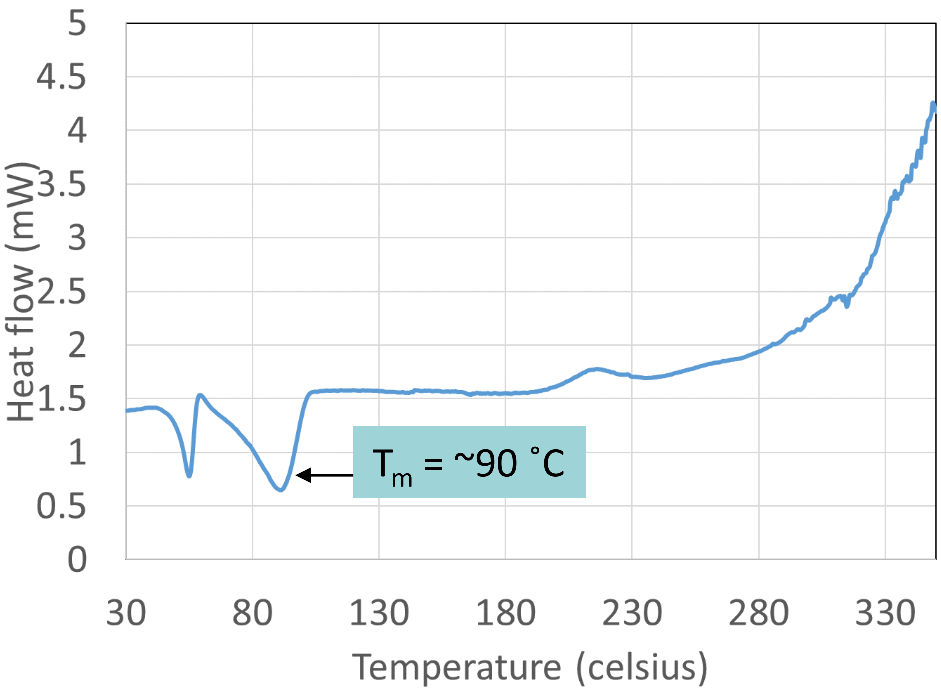
Surlyn disk was cut and then heated to induce healing.

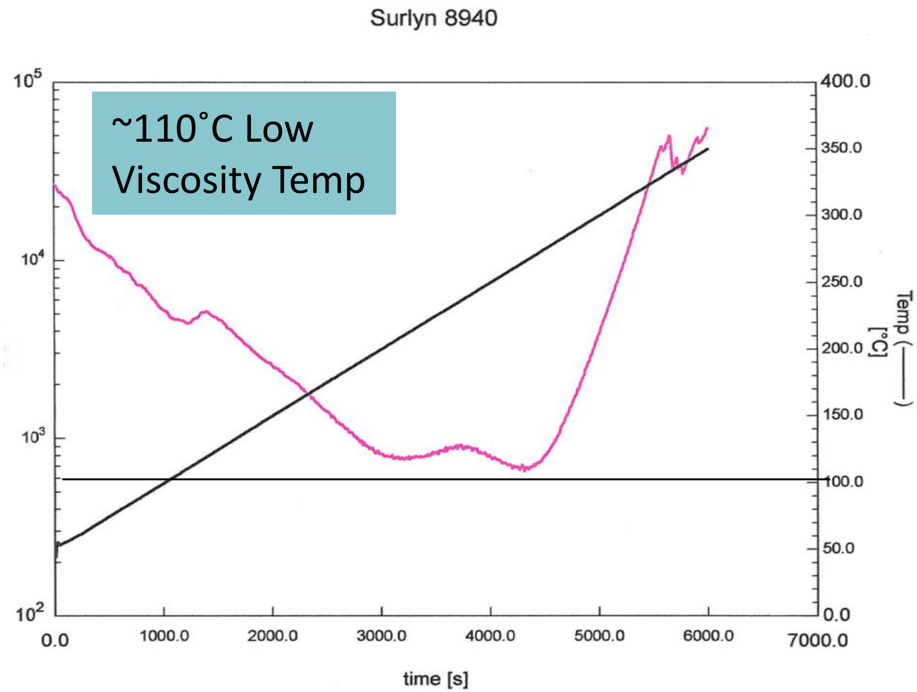
1st healing cycle → 67% recovery w/o additional heating

Elevated heating after mending activates ionic crosslinks.

Achieved 90-97% recovery when samples were dwelled at 70˚C.

Film Processing





Surlyn films were processed by using a hot press at 115 ˚C for 1.5 hrs.

Dielectric Breakdown: Kapton vs. Surlyn

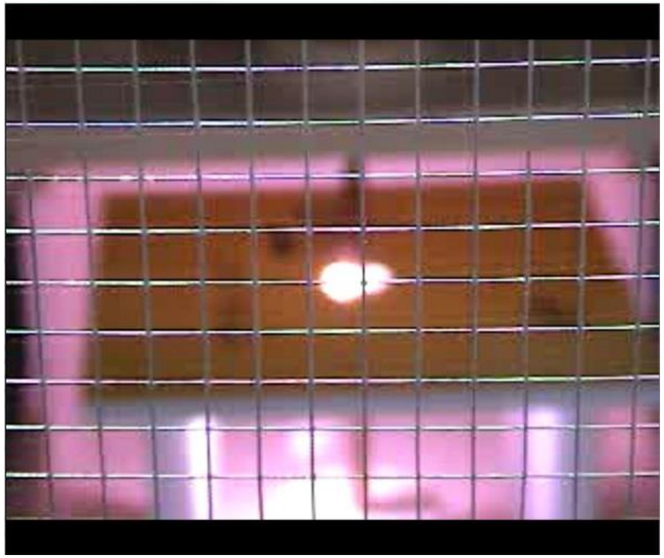
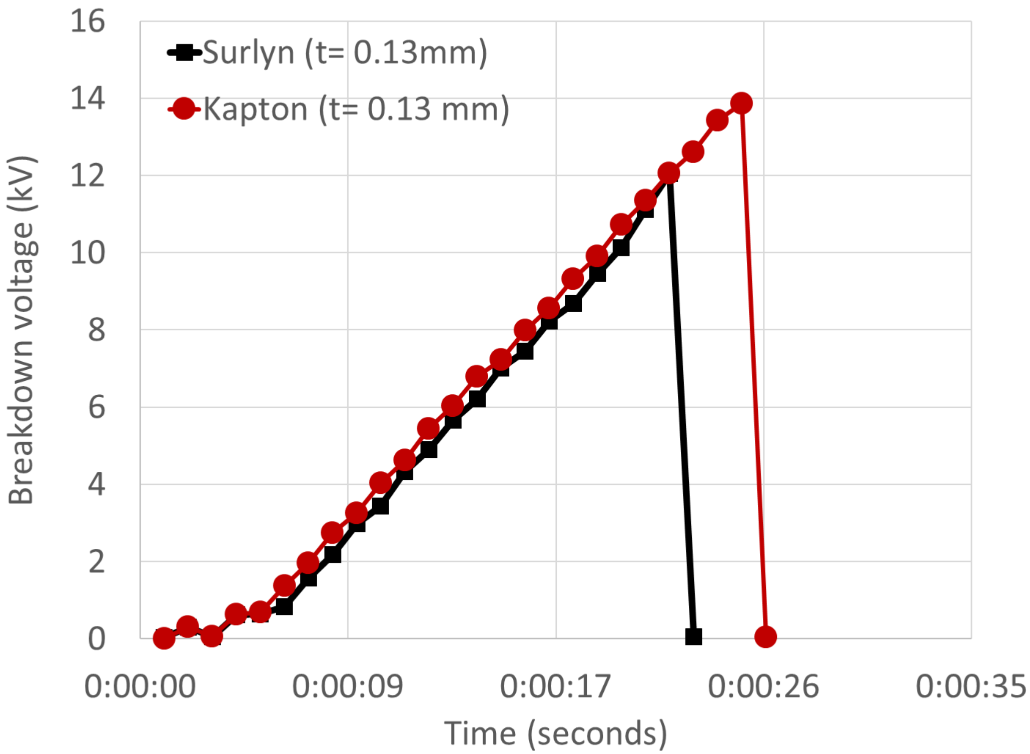
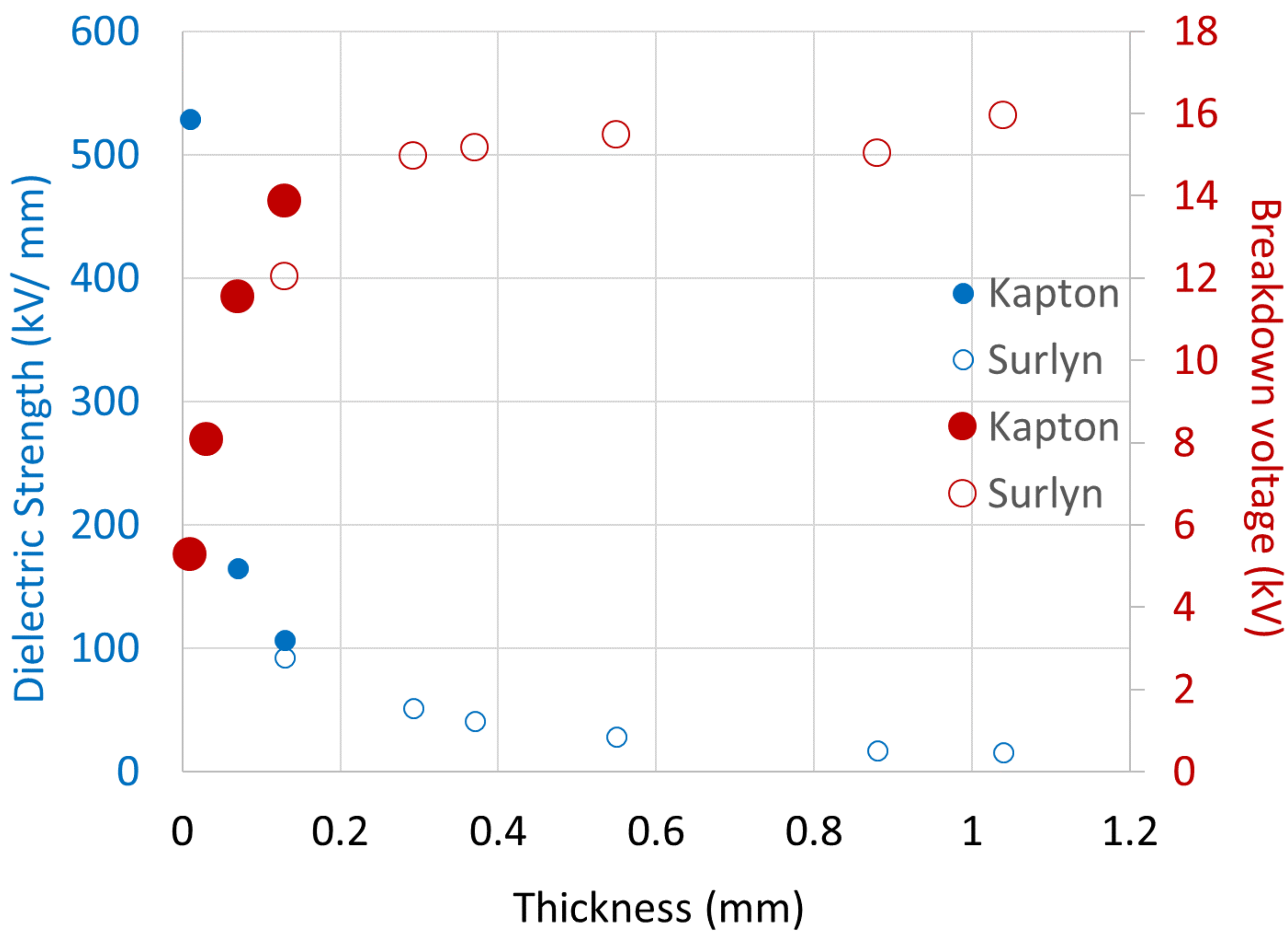


Image of arcing during breakdown.

Eaton High Voltage Test Rig
Output voltage AC: V_{max} 60 kV (~ 84 kV DC)

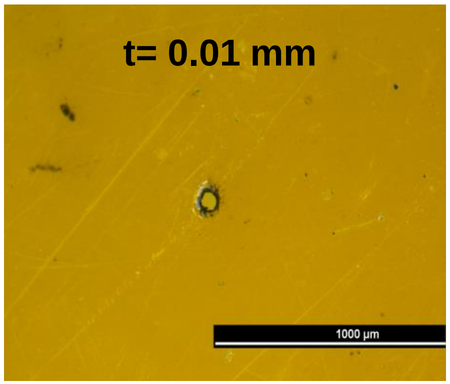


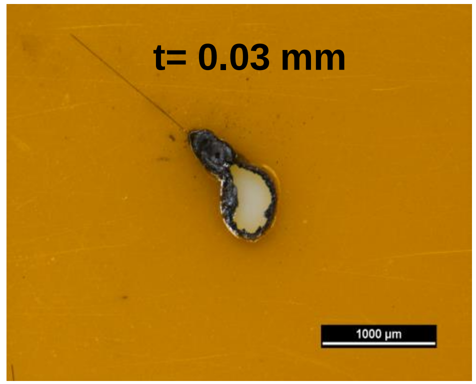
Effect of thickness on dielectric breakdown

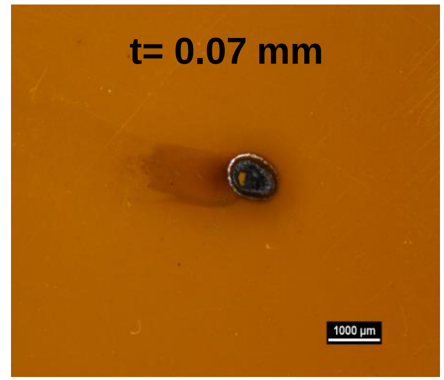


Dielectric Failure Modes in Kapton vs. Surlyn

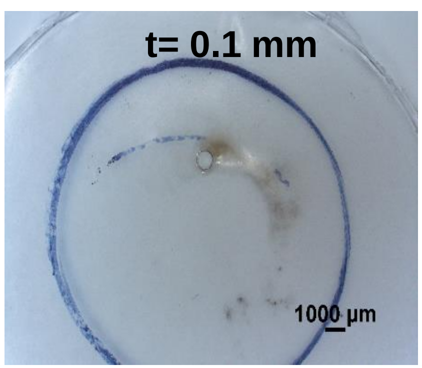
Kapton Films: Punctures and charring observed after testing

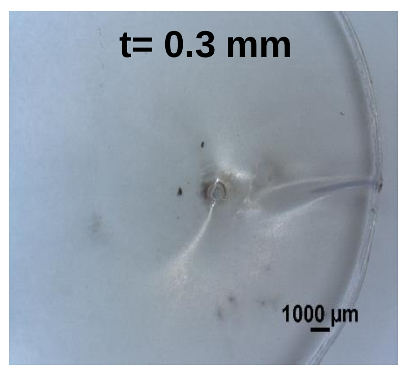


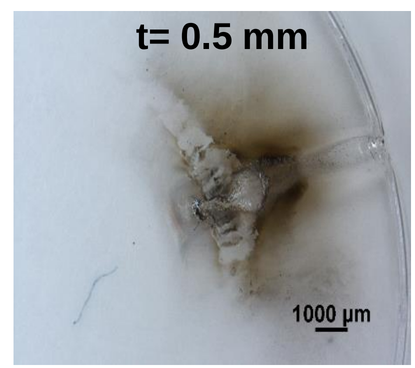




Surlyn Films → Punctures or thinning in thinner films.
Melting and discoloration in thicker films

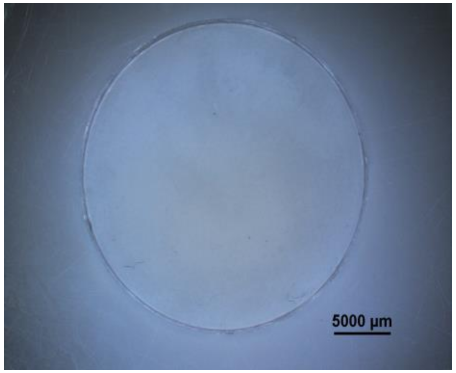


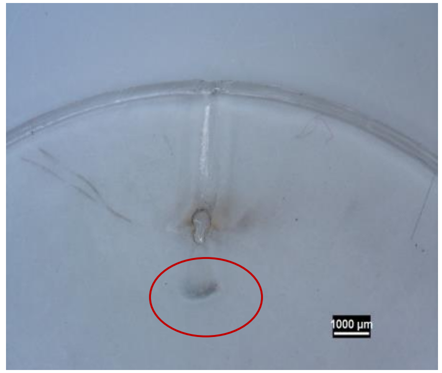


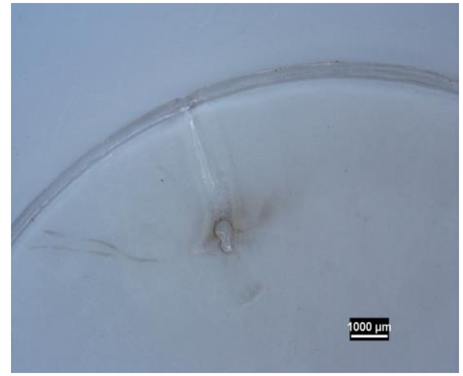


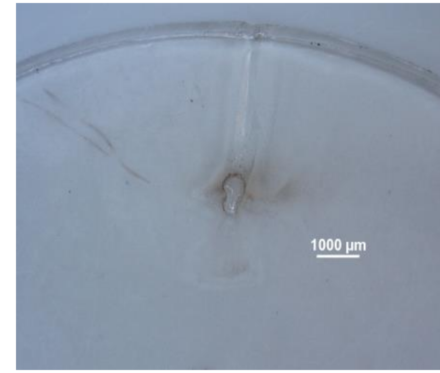
Evaluating Evidence of Healing in Surlyn

Surlyn ~0.33 mm thickness

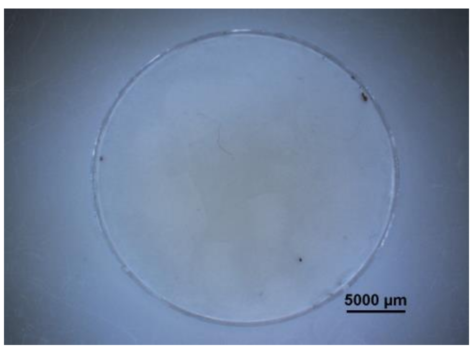


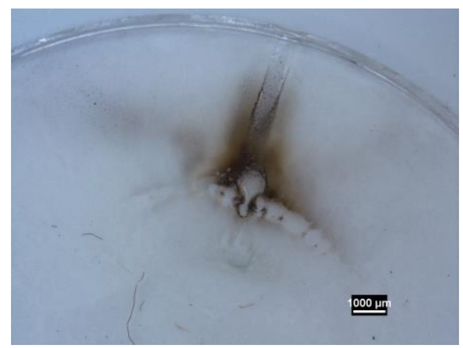
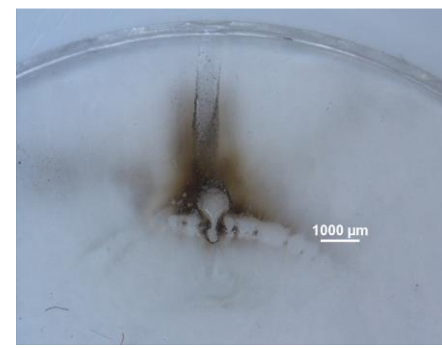






Surlyn ~0.55 mm thickness

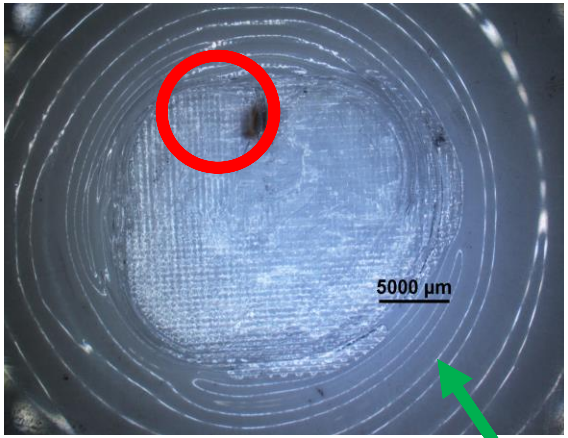


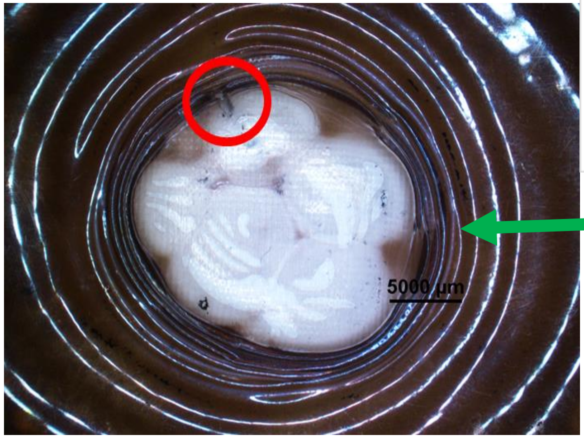
Surlyn did not show evidence of healing at the most severe damaged site, but some discoloration changes were observed in 0.33 mm and 0.55 mm thick samples by day 7 of exposure to 70˚C dwell temperature.

Layered Perfluoroalkoxy-Surlyn Films

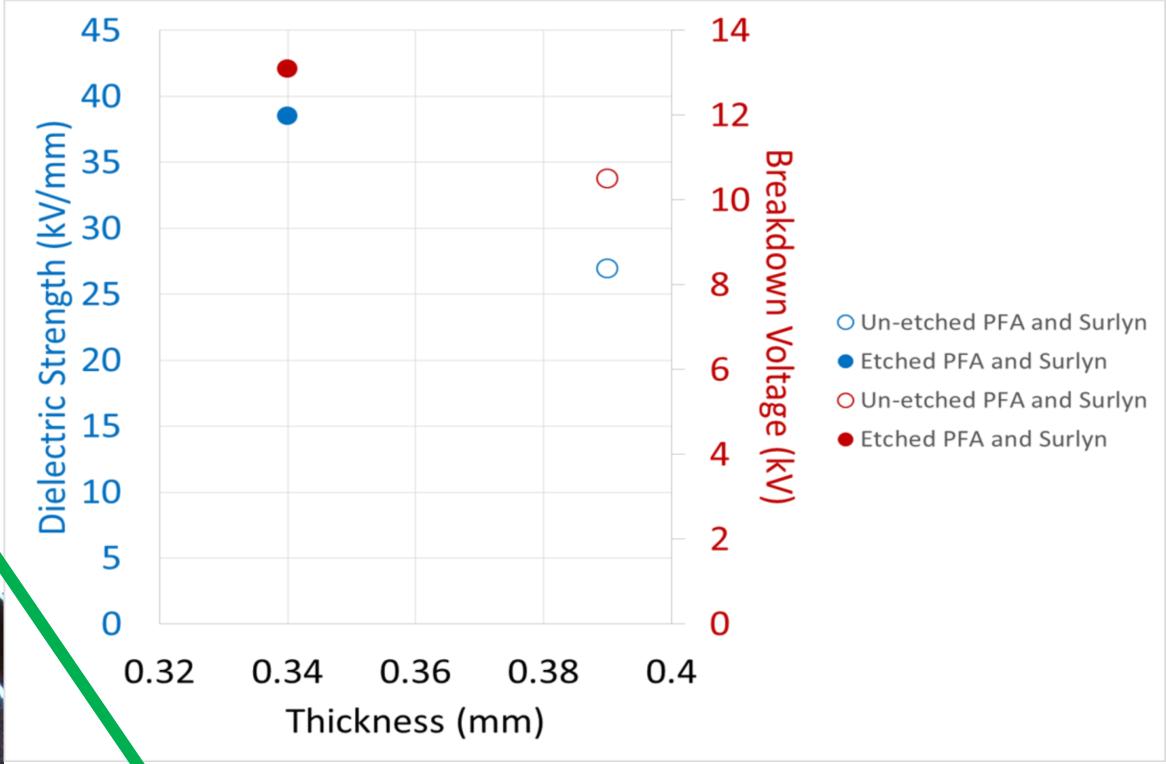
Surlyn was melt-fused with perfluoroalkoxy (PFA) films to enhance breakdown strength and to minimize severity of damaged site to enhance chances of healing.



Not etched



Etched

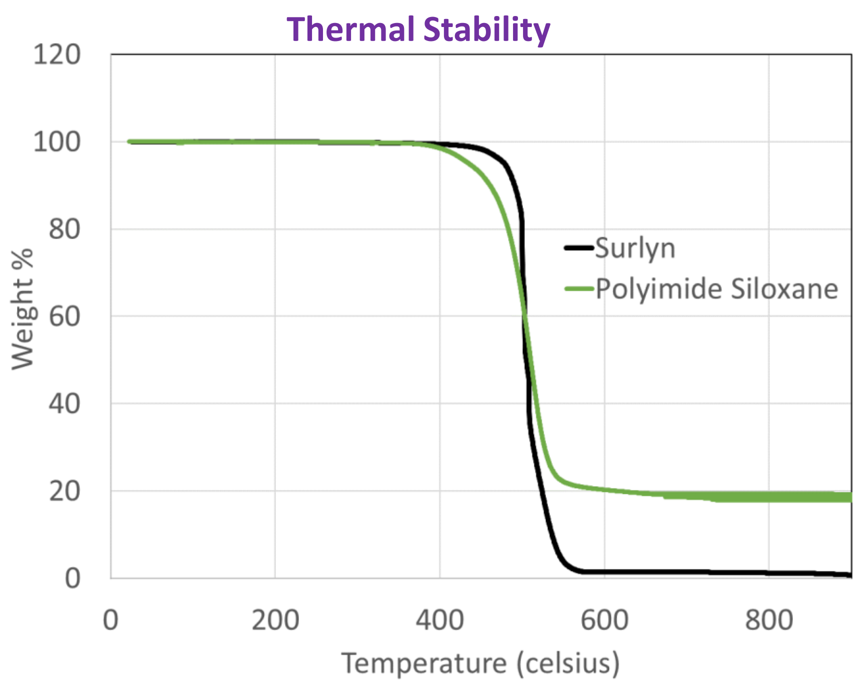


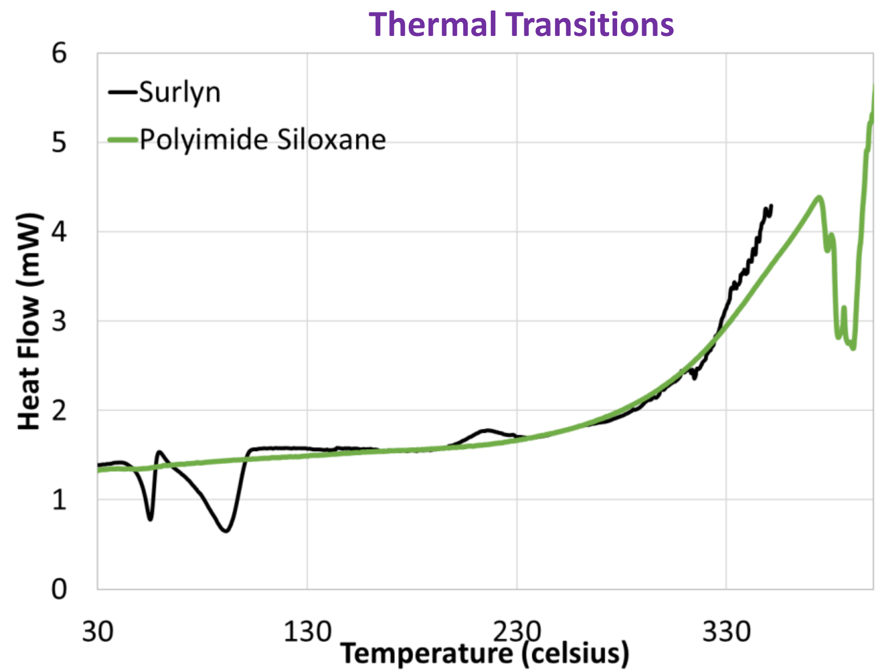
Wrinkling in PFA formed upon melting and flowing of Surlyn pellets.

*Small puncture still observed after breakdown.

Polyimide Siloxanes

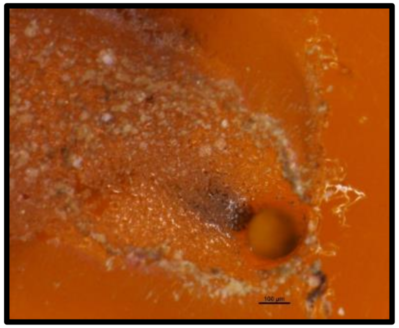
Silicone polymers have potential to self-heal as a result of siloxane equilibration (ionic crosslinking). Introduction of a polyimide component could further increase the thermal stability and dielectric strength.

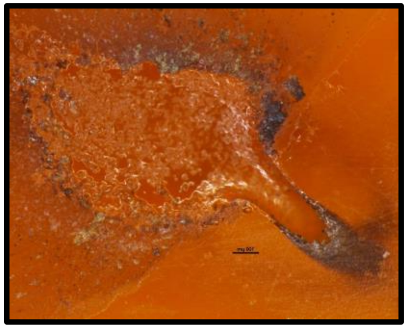




<u>Breakdown voltage</u>
24.8 kV @ 0.63 mm thickness

<u>Dielectric Failure Mode</u>: Combination of melting and charring





Conclusions

- Strong dependence on dielectric strength and thickness
- Surlyn has lower moisture absorbance than polyimide, but inferior dielectric strength
- Polyimide films displayed severe charring at max. voltage. Surlyn showed some evidence of reversible damage at maximum voltage.
- Charring damage is irreversible.
- External loads are required to facilitate self-healing.
- Polyimide siloxane show good dielectric strength, but chain mobility restrictions and charring from the polyimide component make it difficult for healing to occur.

Acknowledgements

- Funding Program: Convergent Aeronautics Solutions (CAS) Program
- NASA Internship Program
- NanoSonic Inc.— Polyimide siloxane films

Film Processing