Conductive Fusion Technology

Advanced Die Attach Materials for High Power Applications

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▪ Overview

- Background
- Concept
- Summary of Invention
- Properties and Reliability
- Conclusion

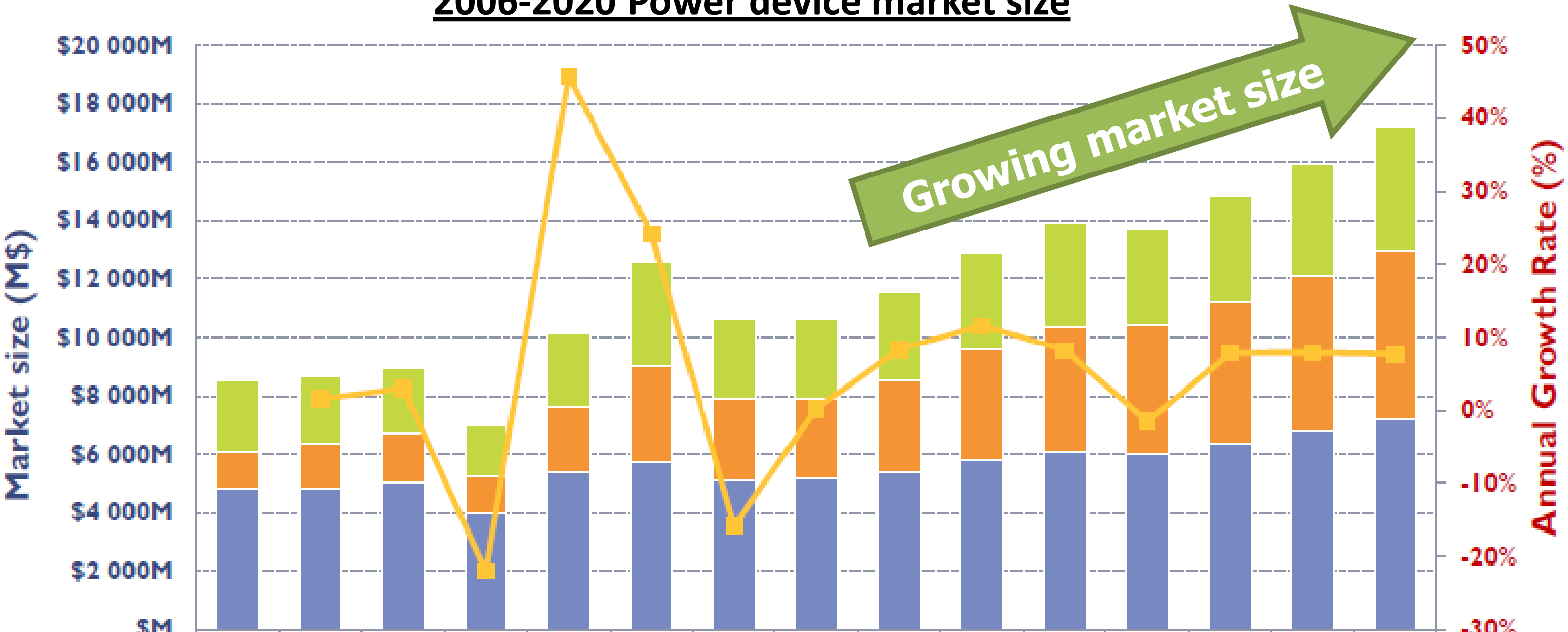
▪ Background

Expanding the power electronics market

Increase in demand for products that are energy saving and reduce environmental footprint

Increase our attention to power electronics

2006-2020 Power device market size



	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Power IC	$2 458	$2 335	$2 218	$1 708	$2 562	$3 587	$2 690	$2 744	$3 007	$3 278	$3 573	$3 287	$3 583	$3 905	$4 257
Power Modules (M$)	$1 280	$1 489	$1 709	$1 286	$2 181	$3 298	$2 828	$2 730	$3 173	$3 805	$4 262	$4 458	$4 845	$5 267	$5 714
Discretes (M$)	$4 804	$4 851	$5 011	$3 971	$5 406	$5 719	$5 098	$5 169	$5 352	$5 787	$6 101	$5 979	$6 374	$6 798	$7 229
Growth rate (%)		1,6%	3,0%	-22,1%	45,7%	24,2%	-15,8%	0,3%	8,4%	11,6%	8,3%	-1,5%	7,9%	7,9%	7,7%

Source: Yole's report "Status of Power Electronics Industry 2015

▪ Background

Constantly developing Wide Band Gap (WBG) power devices require:

- Save space and weight
- Lower switching losses
- Operation at higher switching frequencies

Solution

SiC and GaN

On another front…

Emerging issue

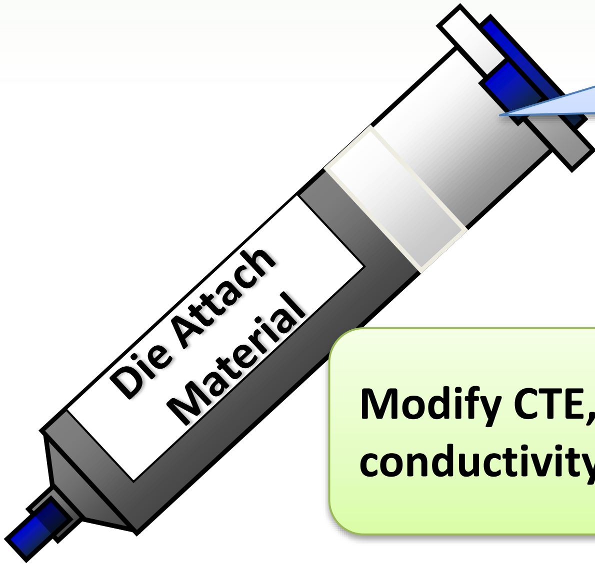
	Si	SiC	GaN
Bandgap（eV）	1.1	3.3	3.4
Electronic mobility（cm2/V.s）	1350	700	1500
C.T.E.（10E-6/k）	2.4	4.4	3.2
Thermal conductivity（W/m.K）	1.3	4.9	1.3
Tj max（deg. C）	150	250	300

The material with higher thermostability is needed for SiC and GaN

Increase in functional temperature

▪ Background

The issue of conventional die attach materials



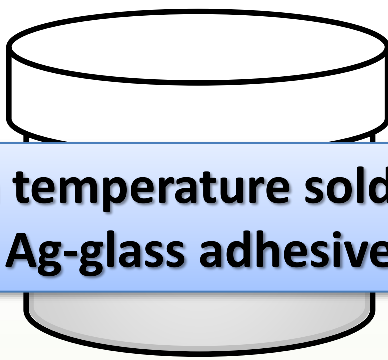
Contain organic additives: Epoxy resin, polymer powder, etc.

Why?

Modify CTE, modulus, thermal conductivity (k), DSS, etc.

Potential problems

- Thermal conductivity degradation
- Bleeding issue
- Limitations of the solvent incompatibility
- Polymer decomposition at high temp.



High temperature solders or Ag-glass adhesives

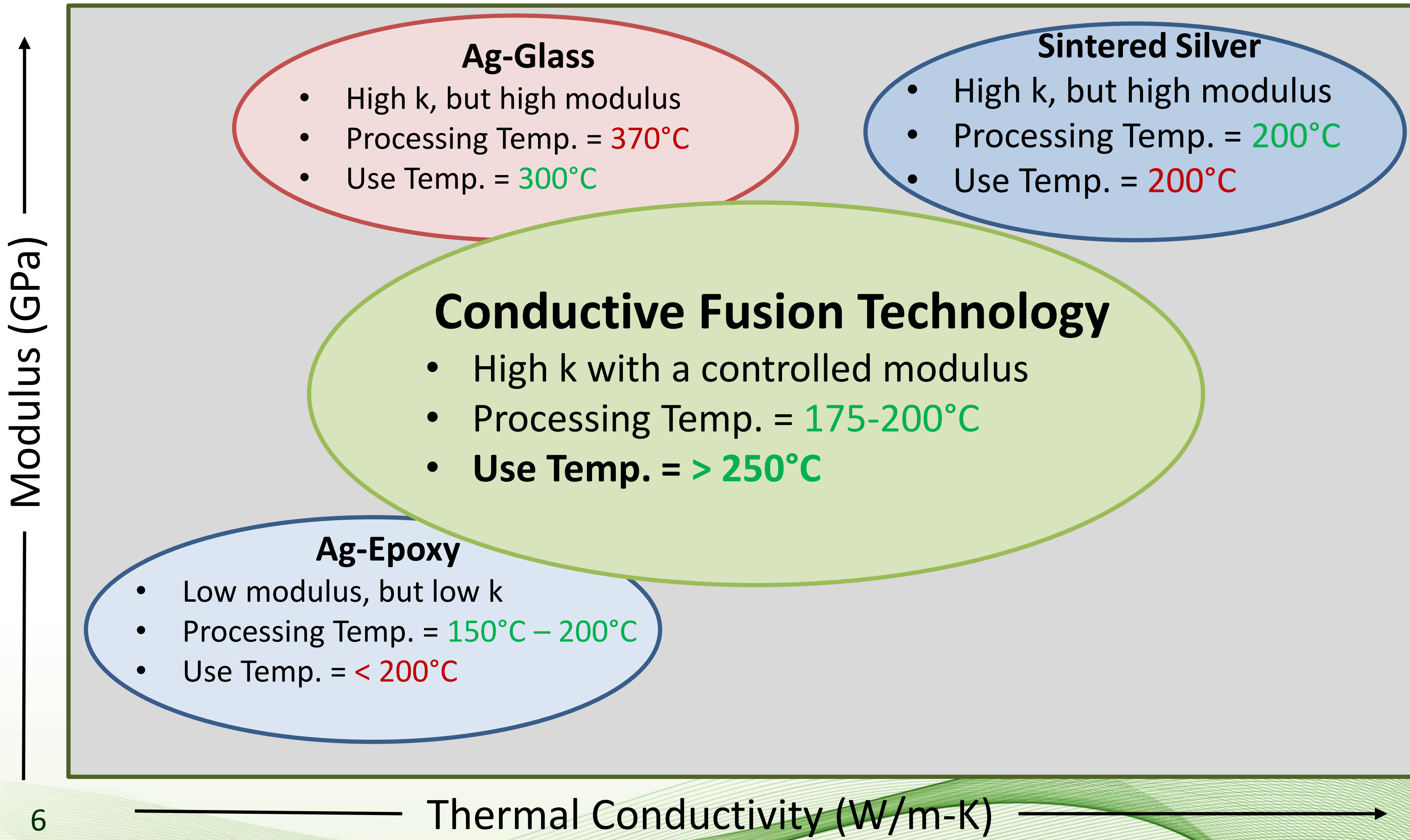
Drawbacks

Do not exhibit low stress die attach properties, and have high temperature processing requirements

New die attaching material is needed.

The Solution: Low stress die attach adhesives with **Soft Modifier**

Ag Die Attach Adhesives



▪ Standard Solder, Ag-Epoxy/Thermoplastic vs. Conductive Fusion Technology

	Data Comparison	PbSnAg Solder	AuSn Solder	Ag-Epoxy, Thermoplastic	Conductive Fusion
Bulk Adhesive	Thermal Conductivity (1-layer k, bulk)	40-60 W/m-K	57 W/m-K	50 W/m-K	**100 W/m-K**
	Storage Modulus (GPa)	14	59	12	**11**
	Density (g/cc)	9	14.7	3-5	**5**
Die Attach Process	DA Temperature	>300°C	>300°C	175-200°C	**175-200°C**
	DA Process Atmosphere	Reducing or Flux	Reducing or Flux	Air, or Inert	**Air, or Inert**
Die Attach Properties	Shear Strength (MPa)	15	TBD	20	**30**
	Interfacial Resistance (Rth)	TBD	TBD	~0.06 K/W	**0.007 K/W**
	Effective Thermal Conductivity - keff (3-layer k)	TBD	TBD	7 W/m-K	**75 W/m-K**

100% increase

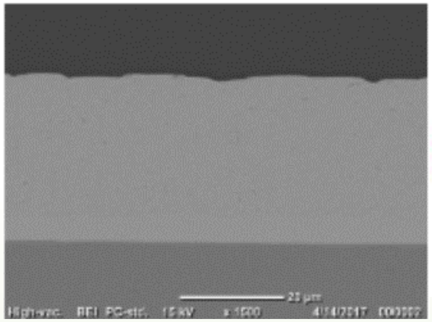
Controlled modulus

Low DA temperature, no pressure or vacuum needed

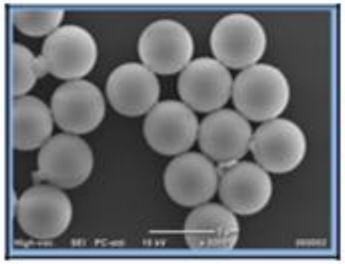
Very good thermal interfaces, great for heat dissipation.

What is Conductive Fusion Technology?

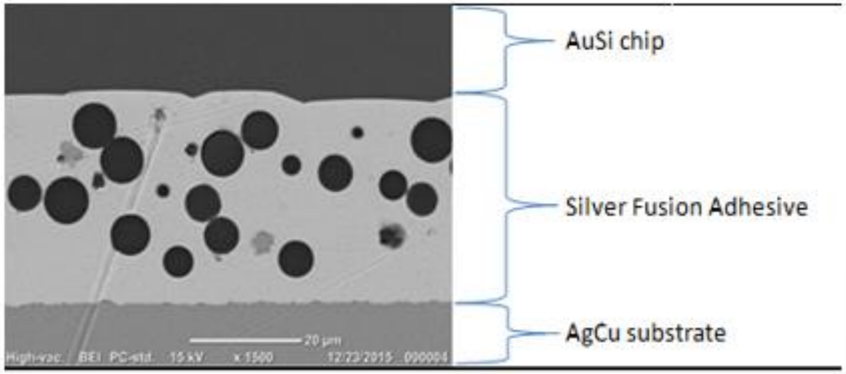
- Sintered conductive component (silver or copper) plus a “soft modifier” stress reliever
    - Sintered system = high thermal conductivity
    - Soft Modifier = acts as CTE buffer, without disrupting heat flow
- Uses: high-power semiconductor applications
- Focus: pressure-less, low temperature sintering technology
- **Goal**: great and dependable material for high temperature applications (250°C)



SEM image of sintered conductive component (silver)



SEM image of “soft modifier”

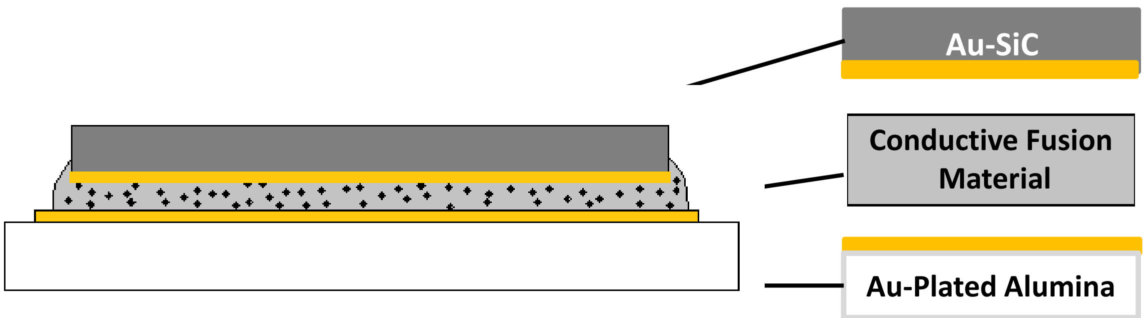


SEM image of sintered silver and soft modifier

Concept

The key factor for new die attach material

- The die attach material acts as a buffer between die and substrate
  - CTE and modulus = very important
  - Low modulus die attach material can relieve stress and improve reliability



CTE (ppm/°C)	Young's Modulus (GPa)
4	220
17	83
7.2	413

Acts as a buffer between two materials with vastly different properties

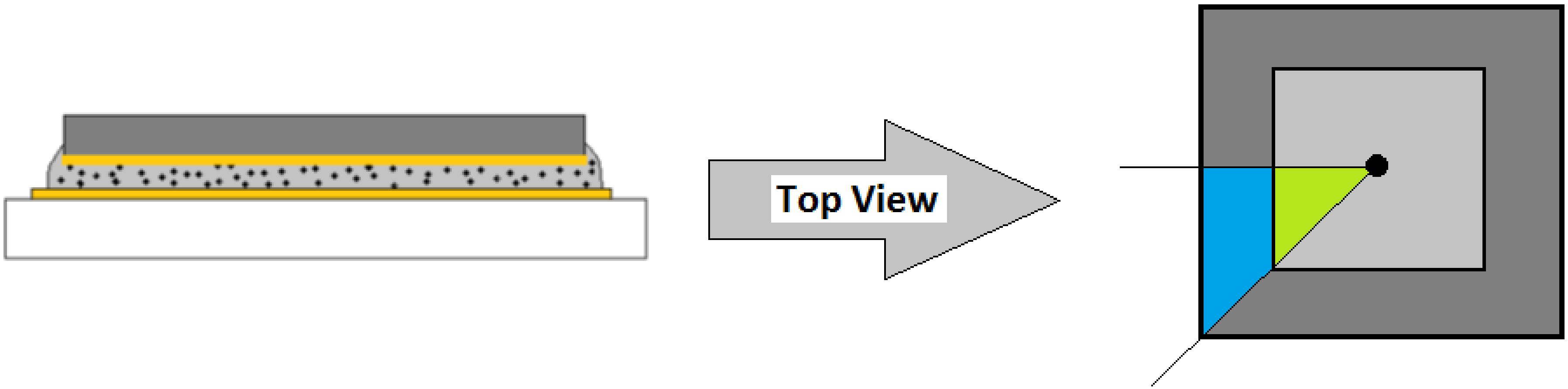
- High thermostability of substrate and die means that our materials needs to exhibit high thermal conductivity.

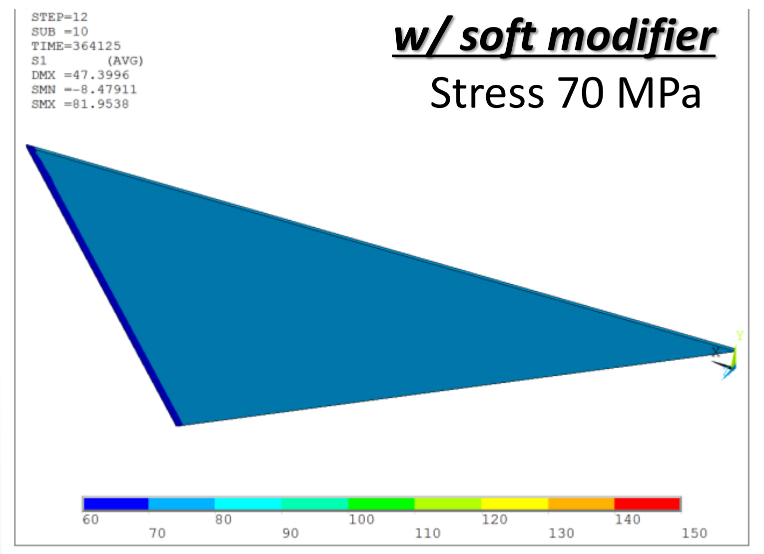
Main Goal: Develop a material that exhibits both high thermal conductivity and reliable stress control.

▪ Simulation Test

With Soft Modifier vs. Without Soft Modifier

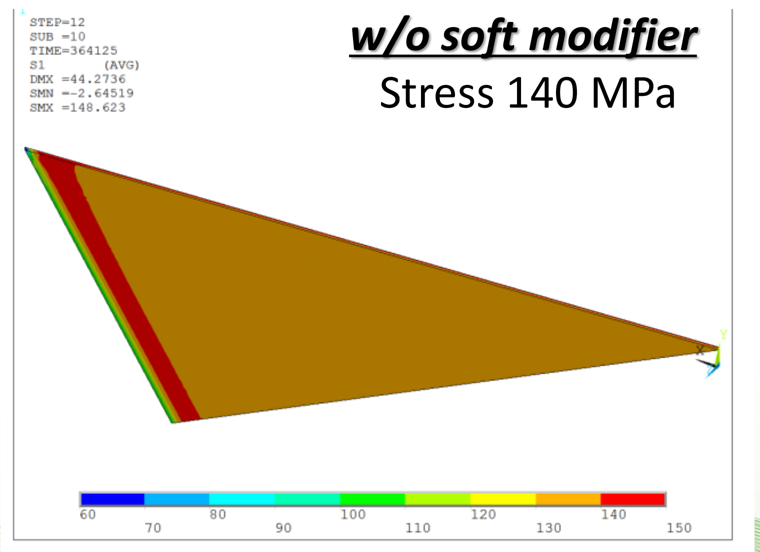
Simulation model





w/ soft modifier

Stress 70 MPa

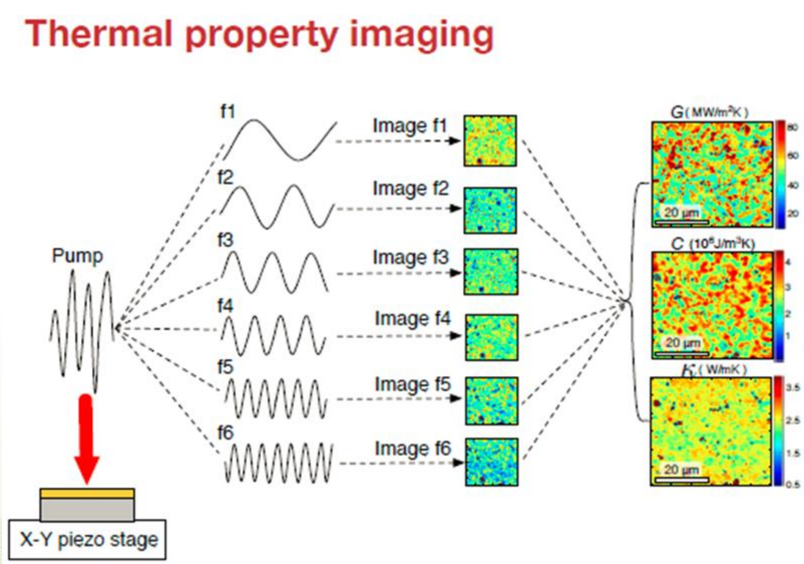


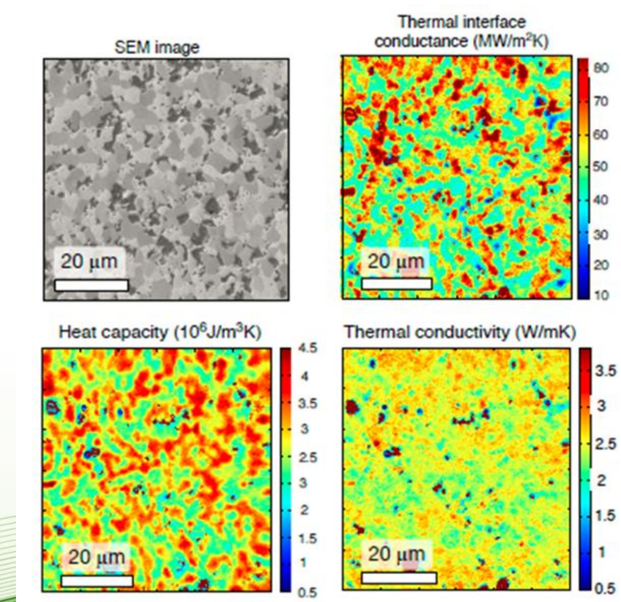
w/o soft modifier

Stress 140 MPa

▪ Thermal Properties Analysis

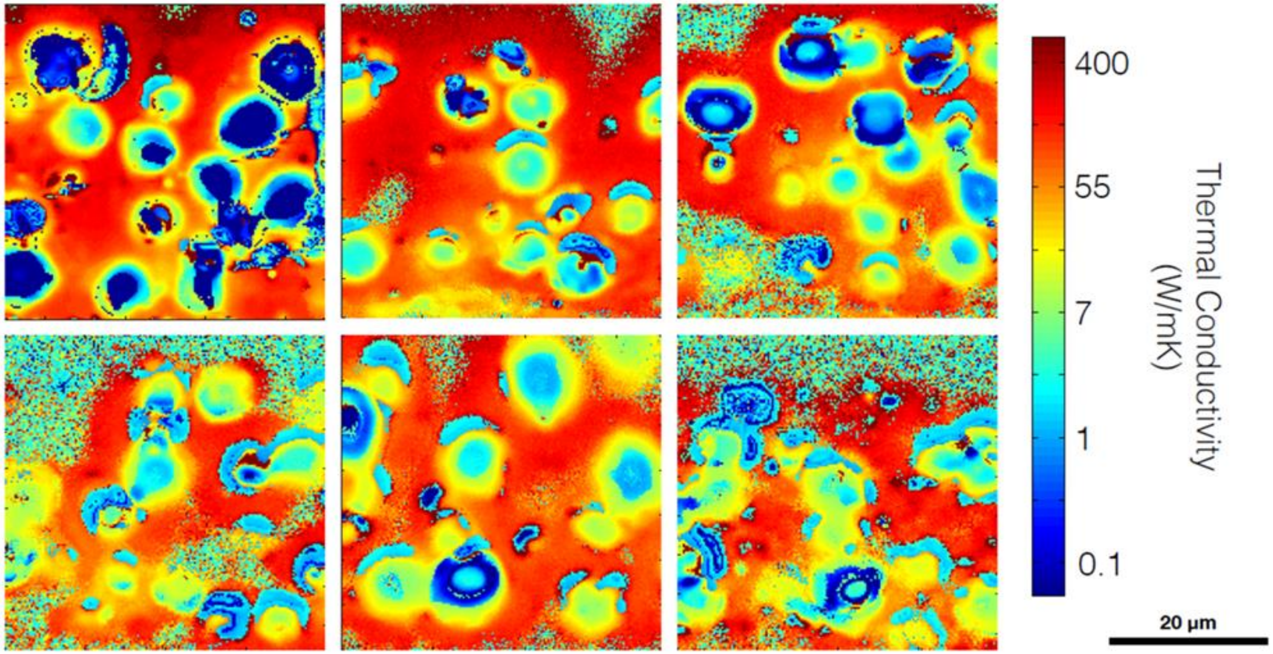
- **Nano-Heat Transfer Lab** – Department of Mechanical Engineering of **Boston University**
  - Fundamental physics of thermal energy at the nanoscale, ultrafast laser measurement techniques, and laser-material interaction
- Thermal Property Imaging – **Frequency Domain Thermoreflectance (FDTR)**
  - Create quantitative, sub-micron maps of a sample's properties such as the **thermal conductivity and specific heat**





Images courtesy of Boston University

▪ Thermal Conductivity Map of the Bond Line via FDTR

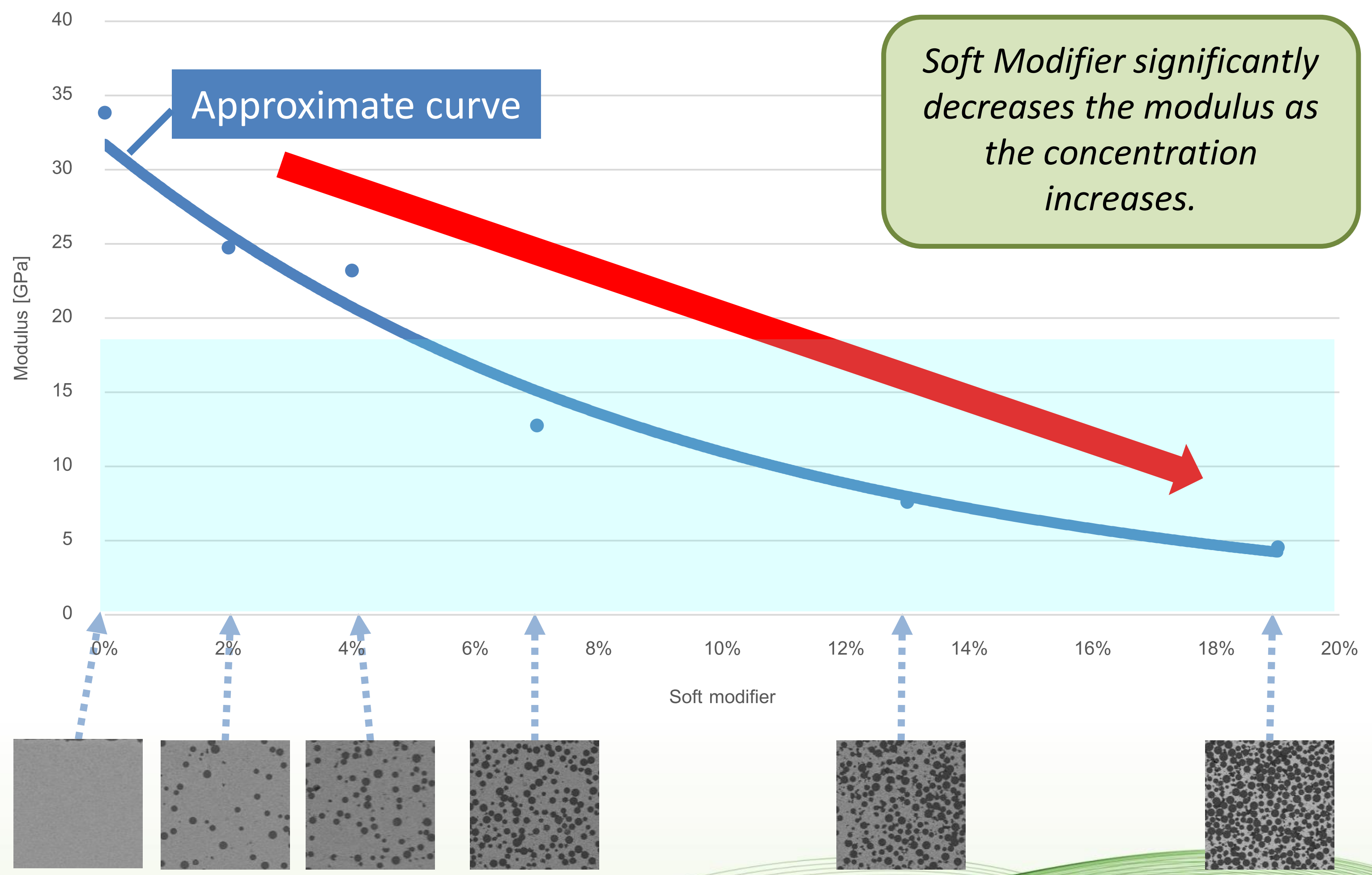


Thermal conductivity of cross-sectioned Conductive Fusion die attach sample via FDTR (Frequency Domain Thermoreflectance)

*Analysis imaging provided by the Nano-Heat Transfer Lab, part of the Mechanical Engineering Department of Boston University

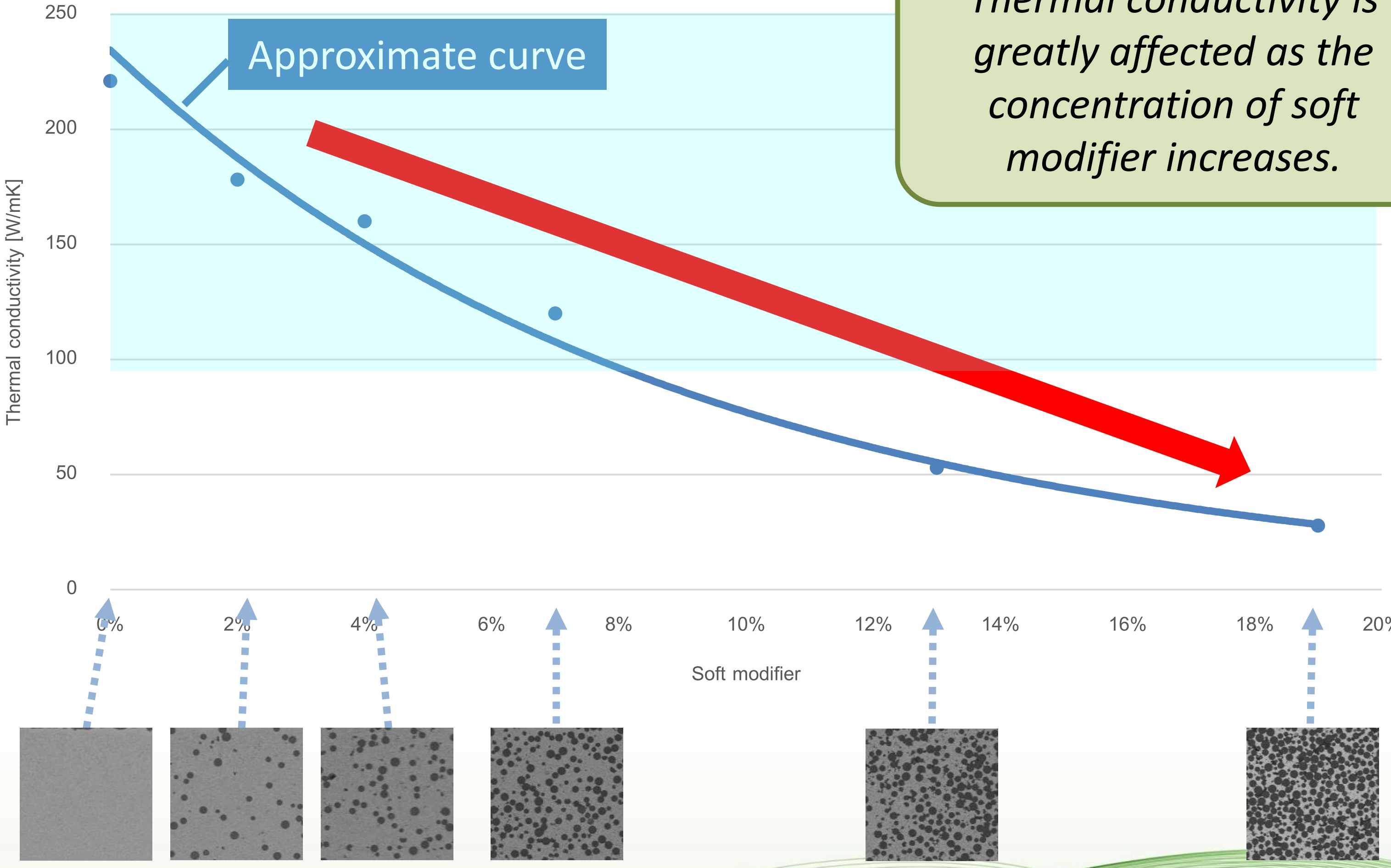
Excellent thermal path – average values above 100W/m-K

▪ Impact on the Storage Modulus vs. Soft Modifier

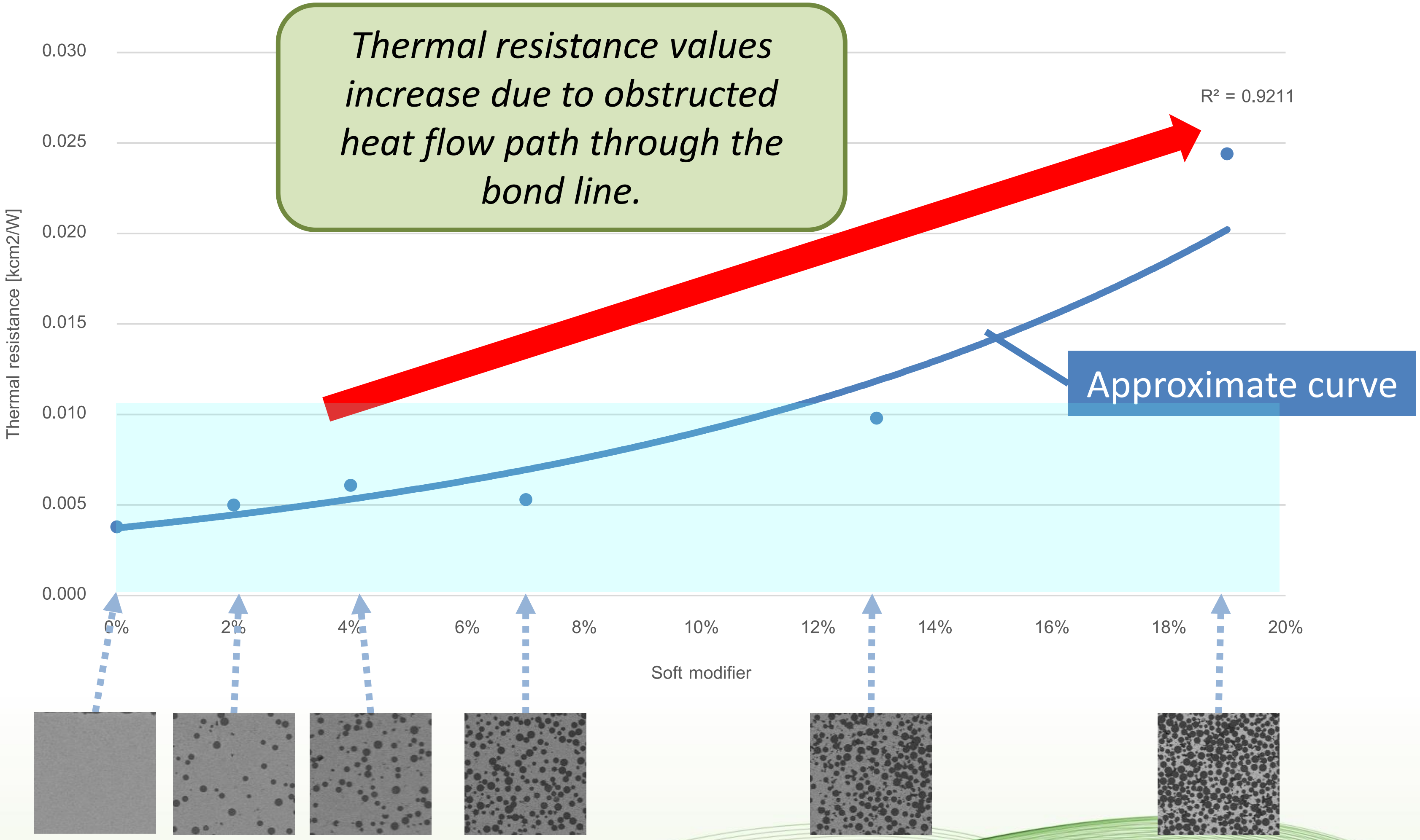


Impact on the Thermal Conductivity vs. Soft Modifier

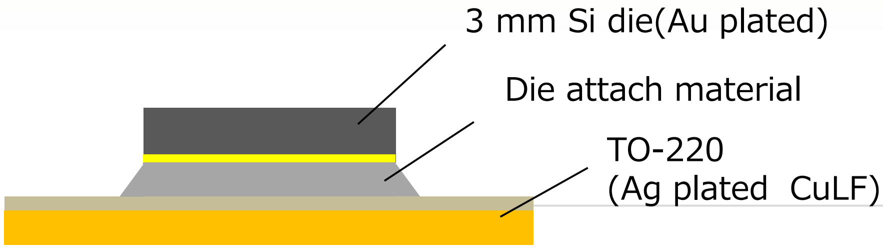
Thermal conductivity is greatly affected as the concentration of soft modifier increases.



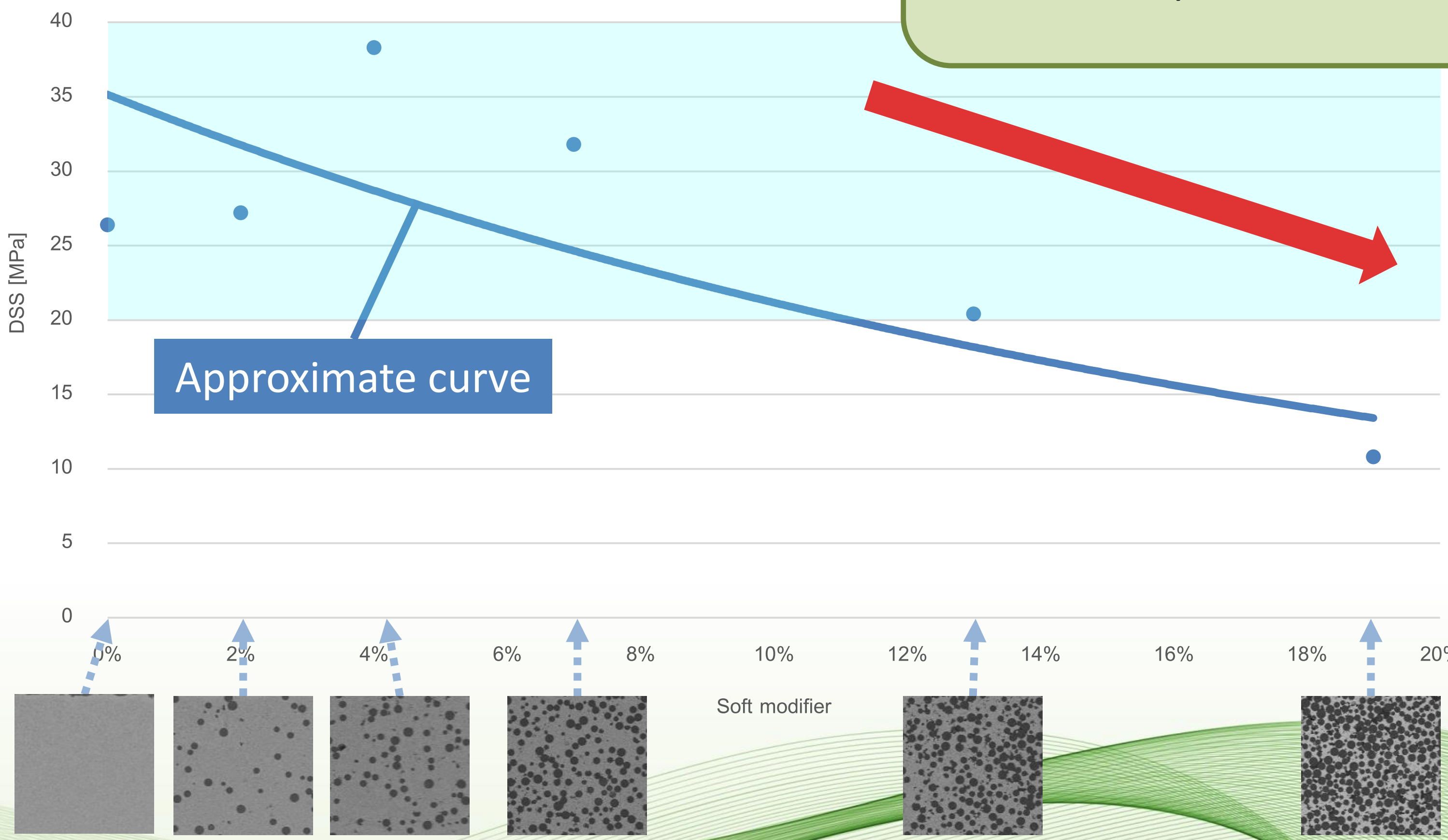
- Impact on the Thermal Resistance vs. Soft Modifier



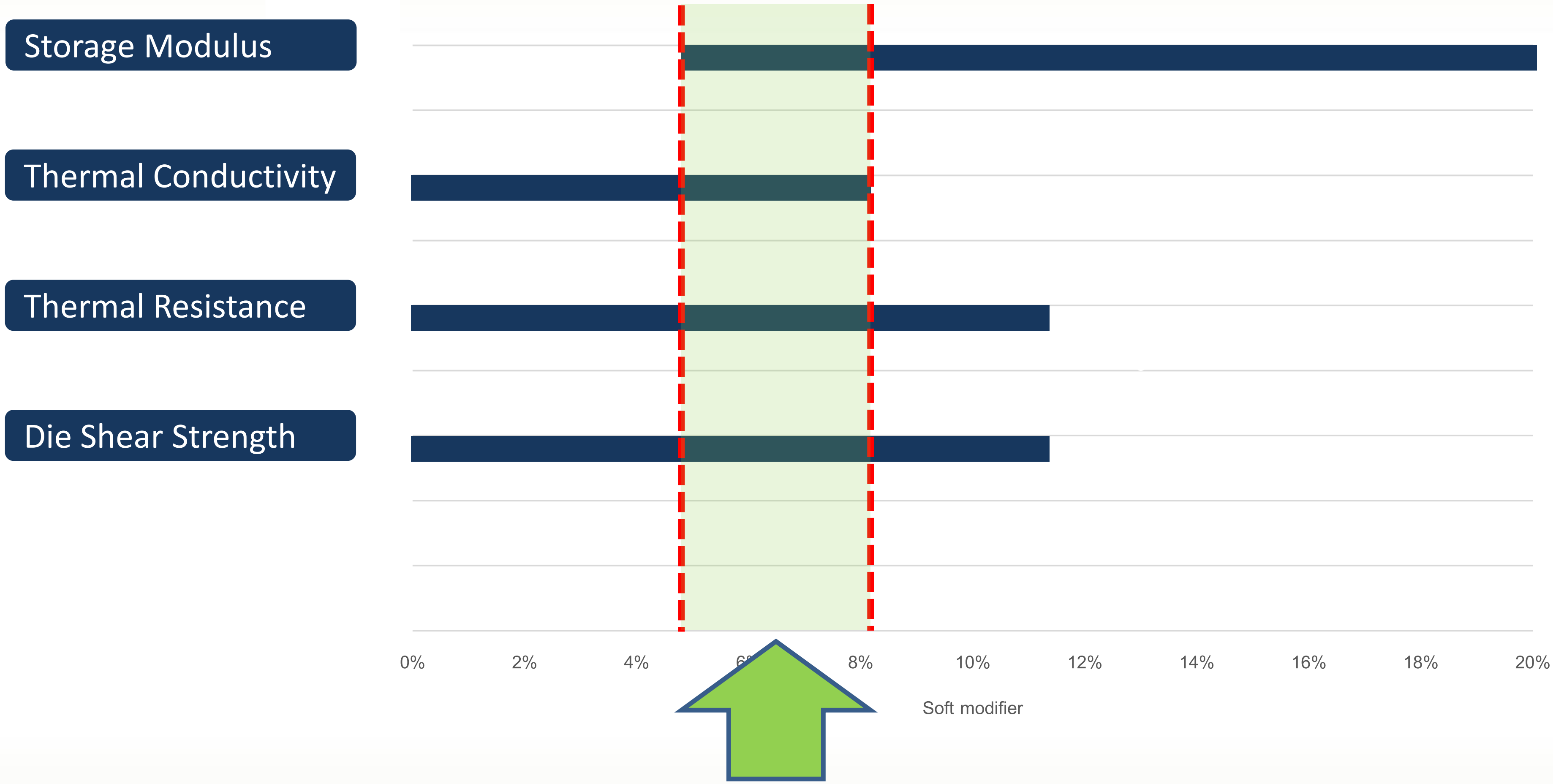
▪ Impact on Die Shear Strength (DSS) vs. Soft Modifier



An increase in soft modifier leads to a decrease in DSS, as expected.



Summary of Results



- **To select amount of stress modifier, all properties must be observed. Need a well-balanced feature between the modulus, thermal, and mechanical properties, which are in a trade-off relationship.**
- **5-8% is conducted as reasonable range for amount of soft modifier.**

Reliability

High Demand for Reliability at Adverse Conditions

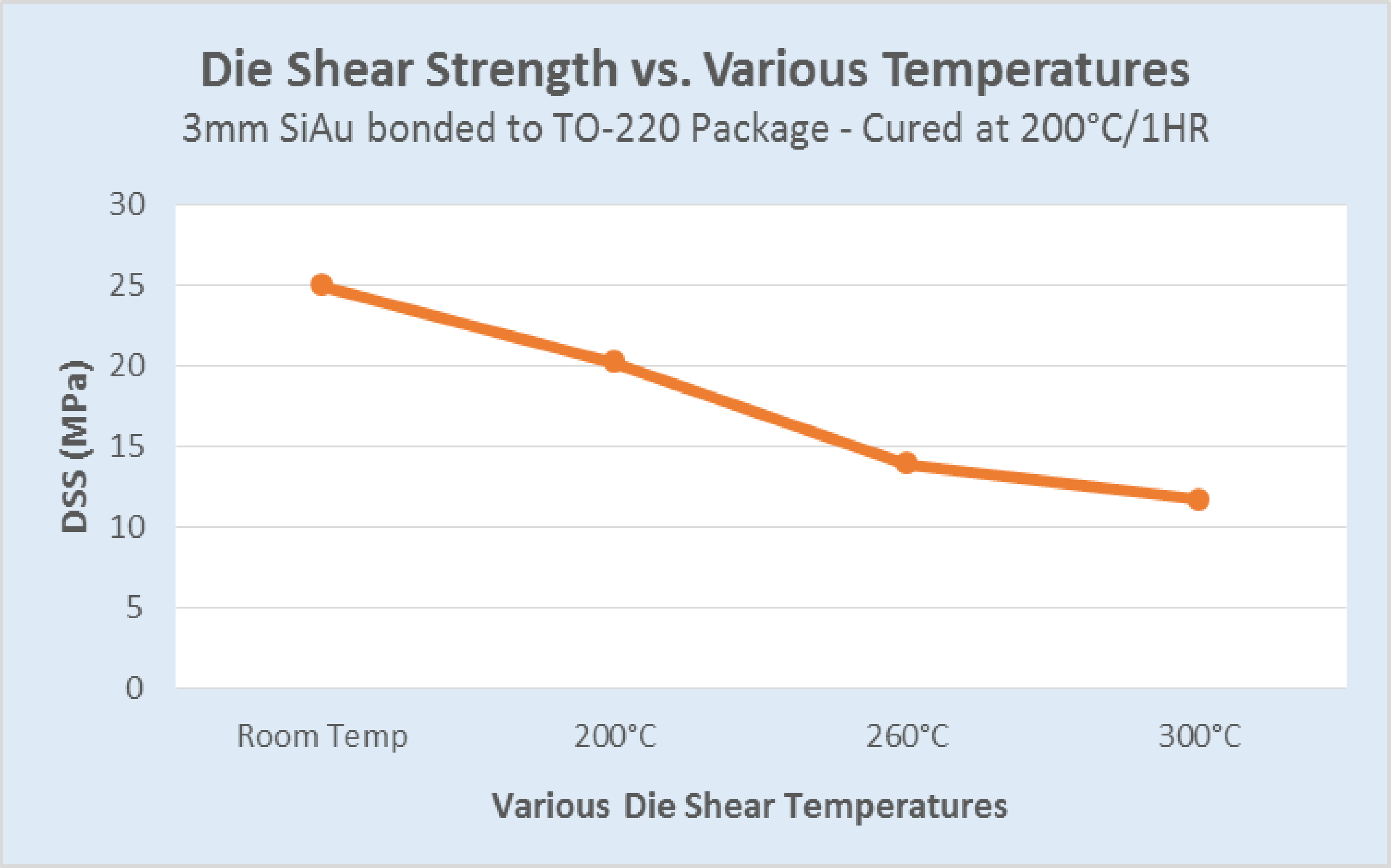
- Hot Die Shear Adhesion Test
  - 200, 260 and 300°C

- Temperature, Humidity Test (THT)
  - 85°C/85% RH for 1000 Hours

- High Temperature Storage (HTS)
  - 250°C for 1000 Hours

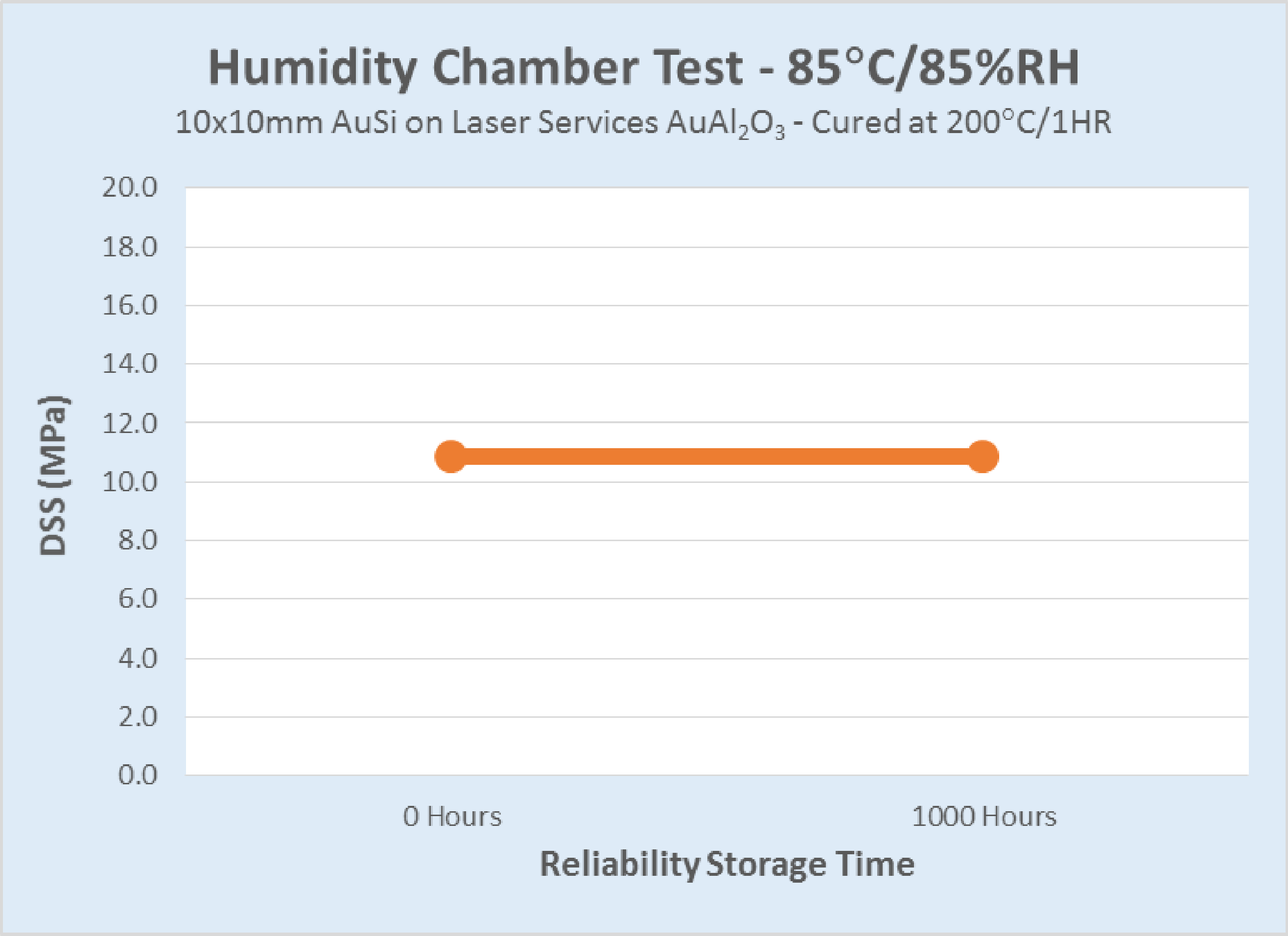
- Temperature Cycling Test (TCT)
  - -55°C/200°C for 1000 Cycles

▪ Hot Die Shear Adhesion

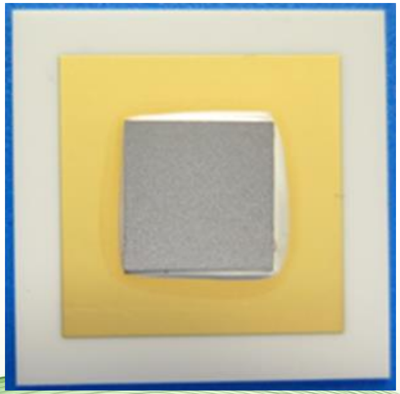


Overall strengths remain rather impressive (above 10 MPa at 300°C)

▪ Temperature, Humidity Test - (85%RH, 85°C)

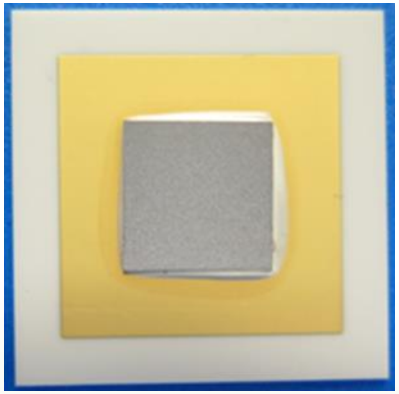


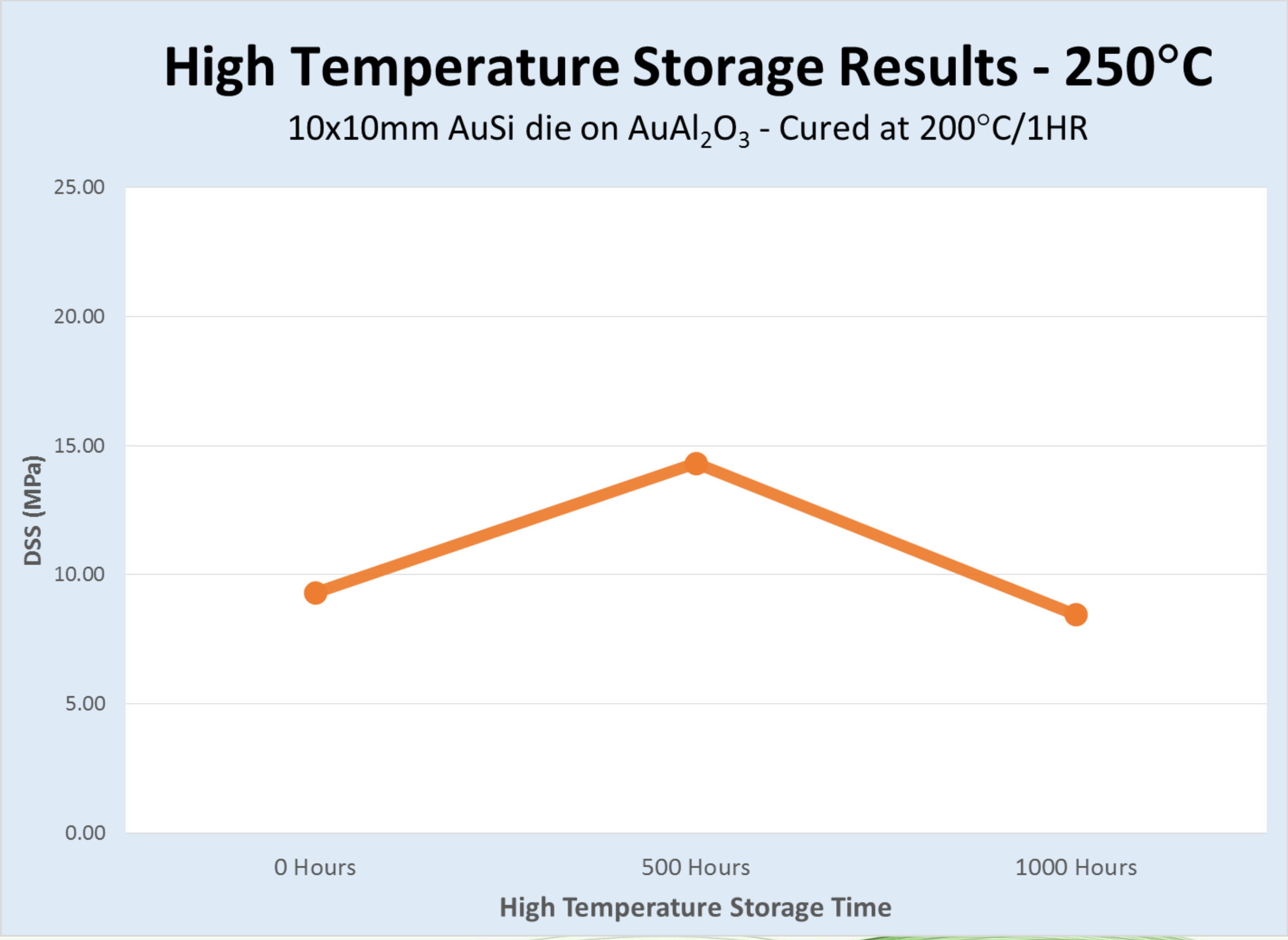
High humidity environment does not promote any degradation after 1000 hours



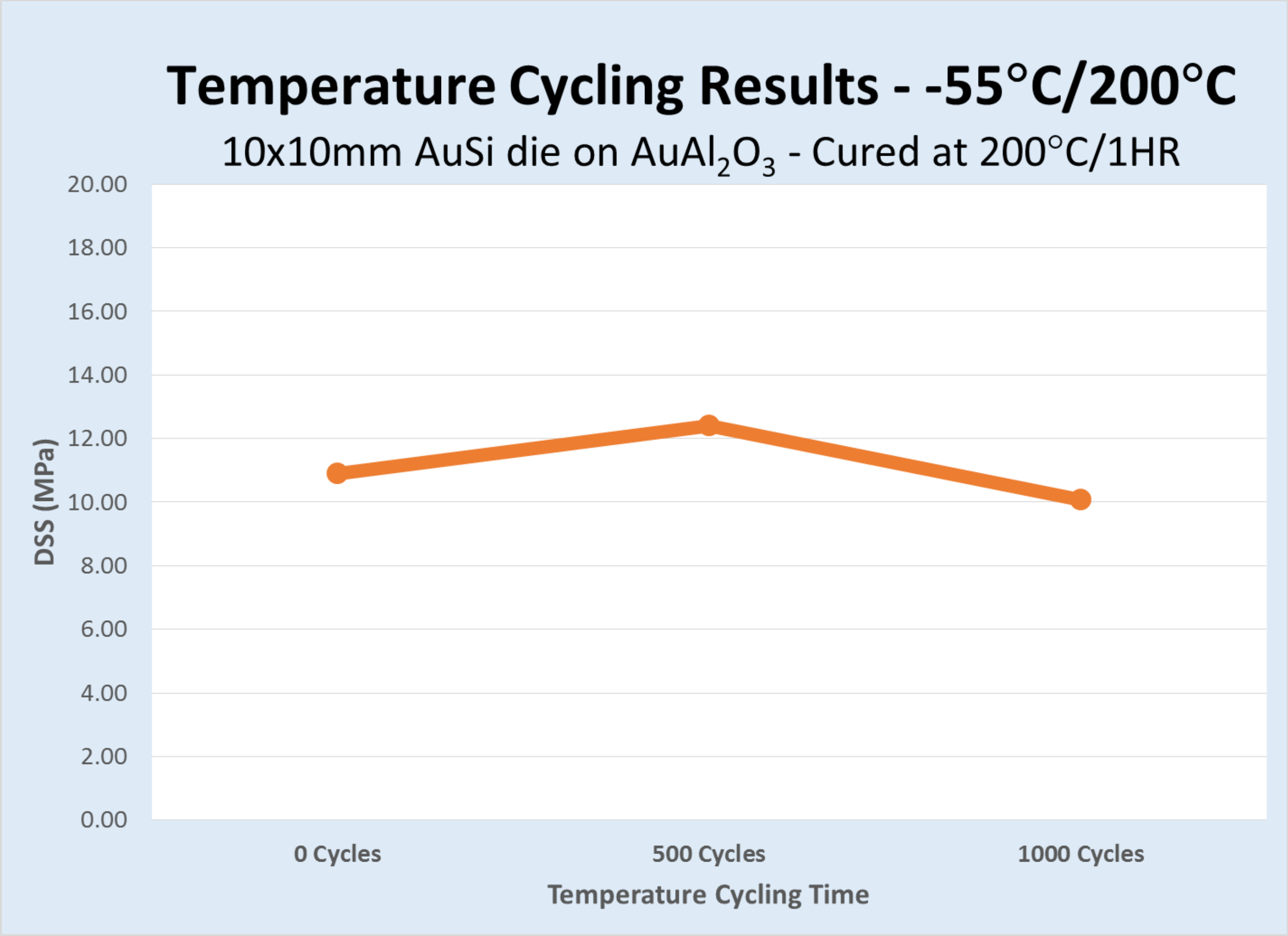
▪ High Temperature Storage at 250°C

HTS results show no degradation after 1000 hours exposure to elevated temperatures.

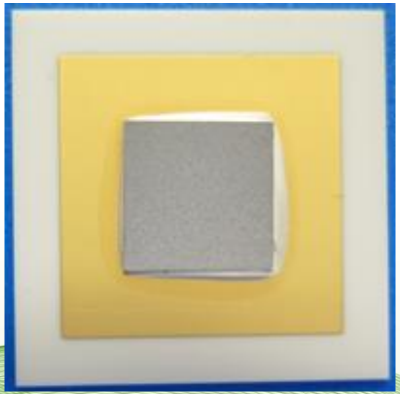




Temperature Cycling Data from -55°C/+200°C



TC results show no degradation after 1000 cycles of exposure to wide range of temperatures



Summary of Conductive Fusion

- Sintered silver adhesive with soft modifier shows:
  - Modulus controlled by adding soft filler, better stress management
  - DSS = > 30MPa
  - HDSS (300°C) = > 10MPa

- Low cure with high use and operating temperature.

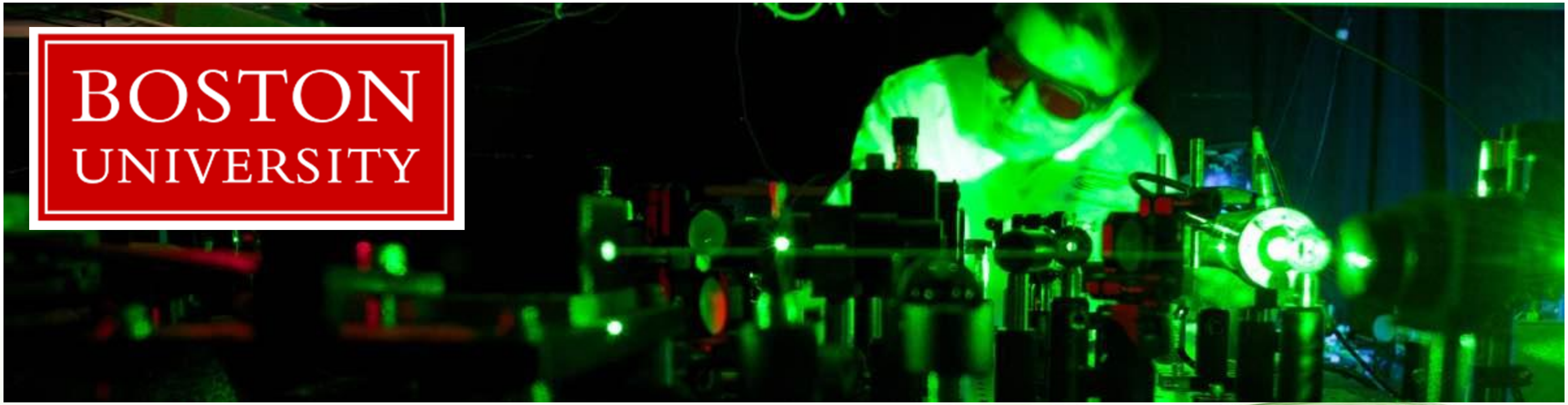
- Reliability:
  - THT (85°C/85% RH) – results show stable DSS results after 1000 hours
  - HTS (250°C) – results show stable DSS results (roughly at or above 8MPa) after 1000 hours
  - TCT (-55°C/200°C) – large area die results show stable DSS values after 1000 cycles.

▪ Acknowledgements

Boston University Nano-Heat Transfer Lab

Mechanical Engineering Department

for thermal analysis using FDTR (Frequency Domain Thermoreflectance)



Thank you for your attention

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