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# Effects of Thermal Aging and Manufacture Induced Stress on Structure Integrity and Performance of TE Module

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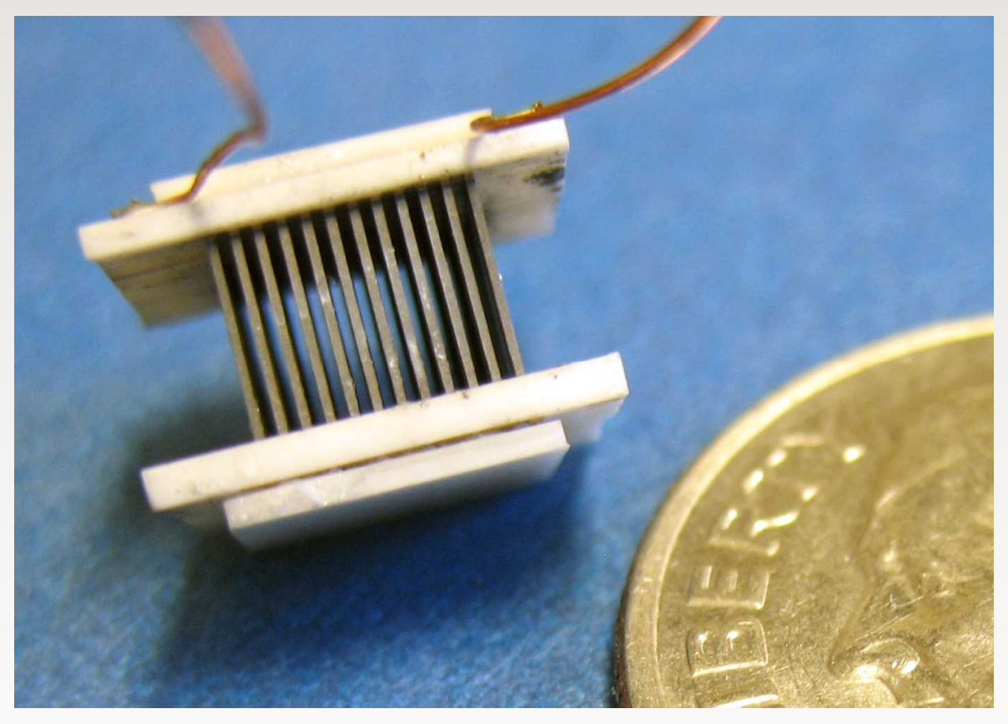
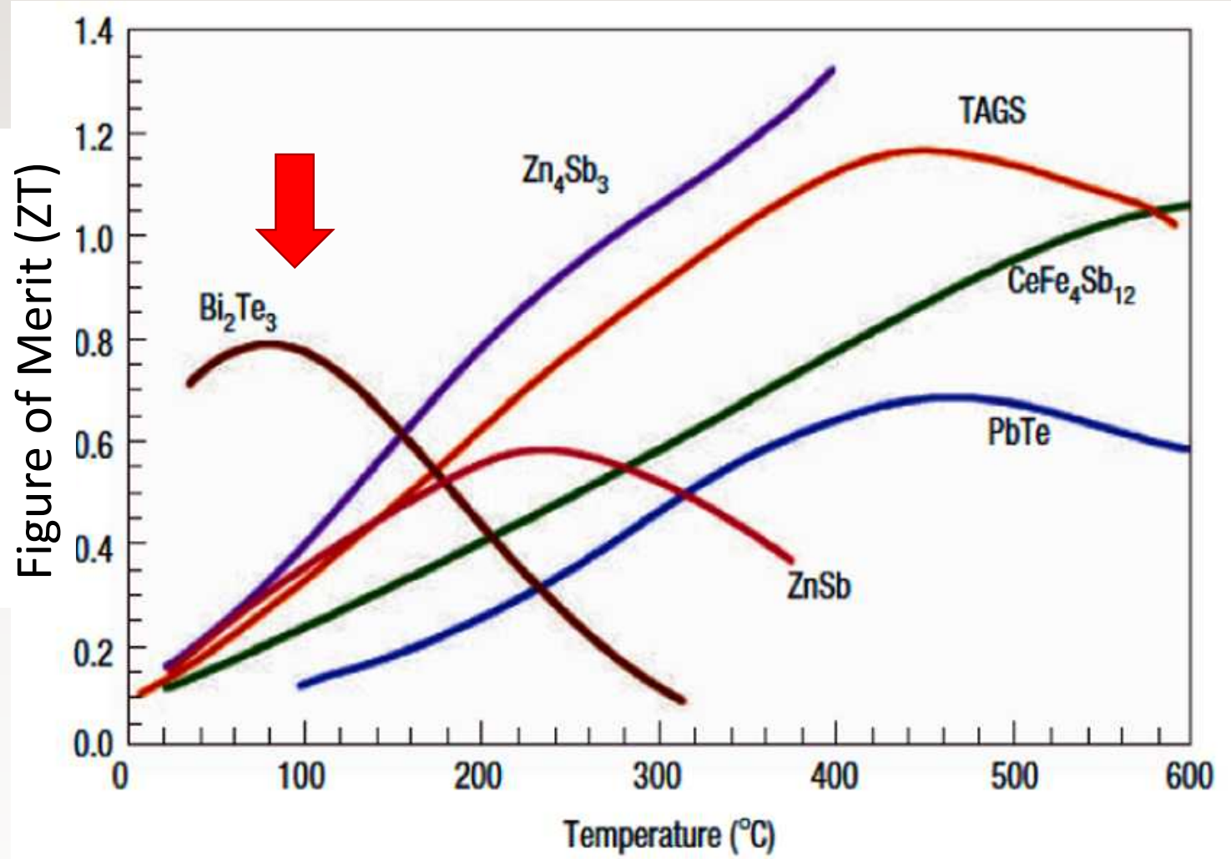
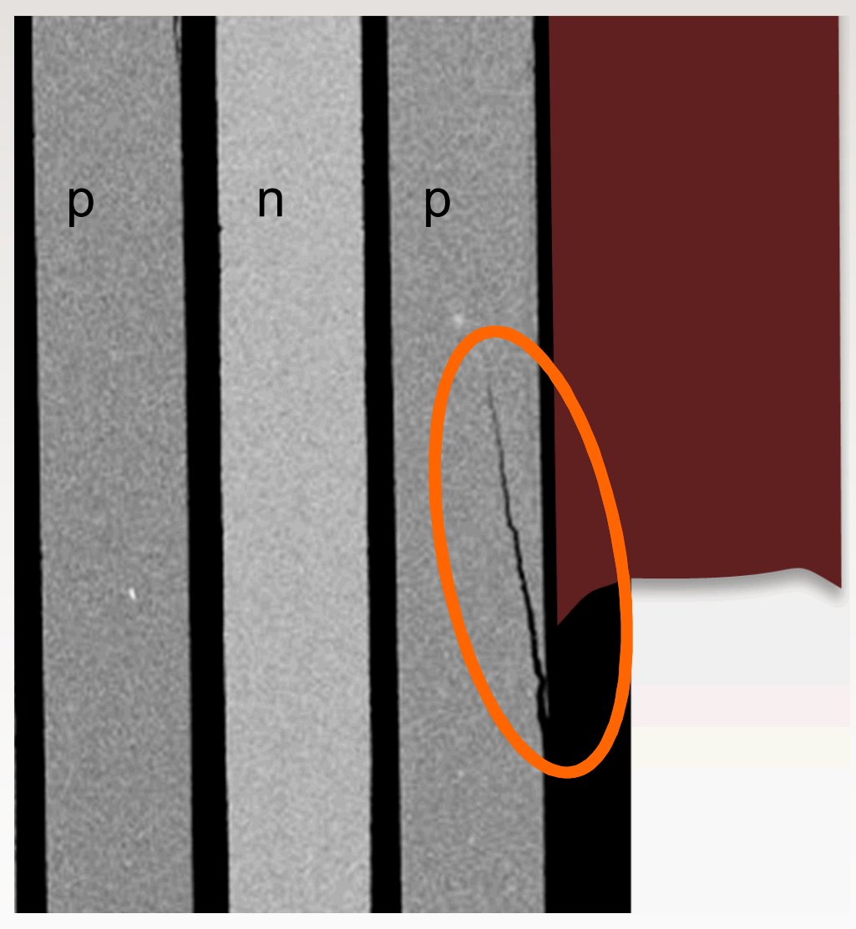
## Mechanical Reliability of TE Module

- $Bi_2Te_3$-based TE module is good for low temperature applications
- The thermopiles may be susceptible to shock/vibration failure at locations of high residual stresses
- P-type: $(Bi_{0.25}Sb_{0.75})_2Te_3$ , N-type: $Bi_2(Te, Se)_3$



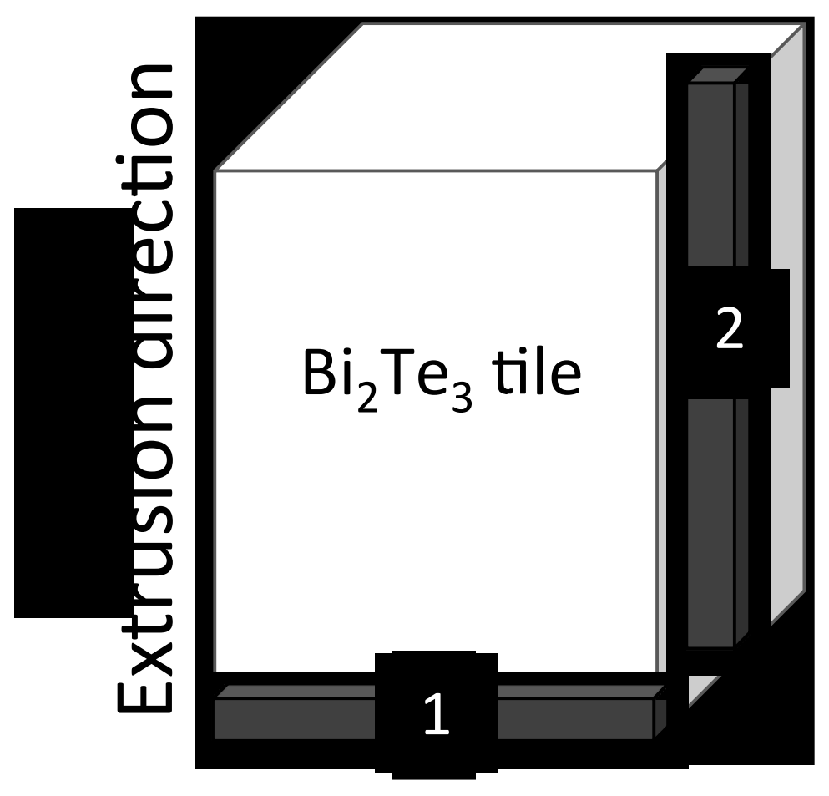


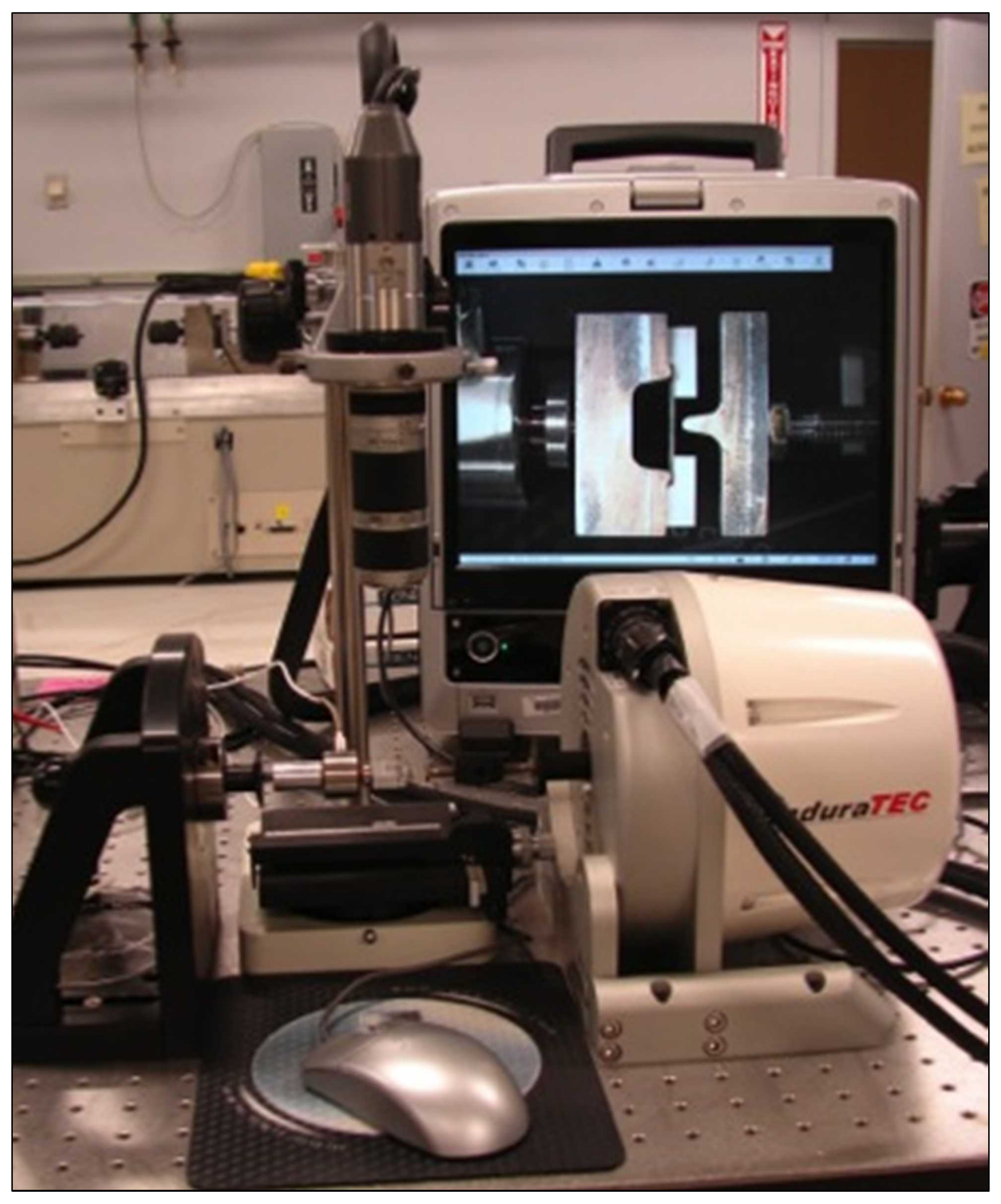
G.J. Snyder et. al., Nature Materials 3, 458 – 463 (2004)



## Mechanical Properties of Fine-Sized $Bi_2Te_3$

- 3-point-bending test for elastic modulus and strength
- Testing at two temperatures, 20 and 200 °C
- P and N samples cut from the bulk rods in the axial (extrusion) and lateral directions
- Specimen dimension: 0.55W x 0.55H x 14L (span) mm

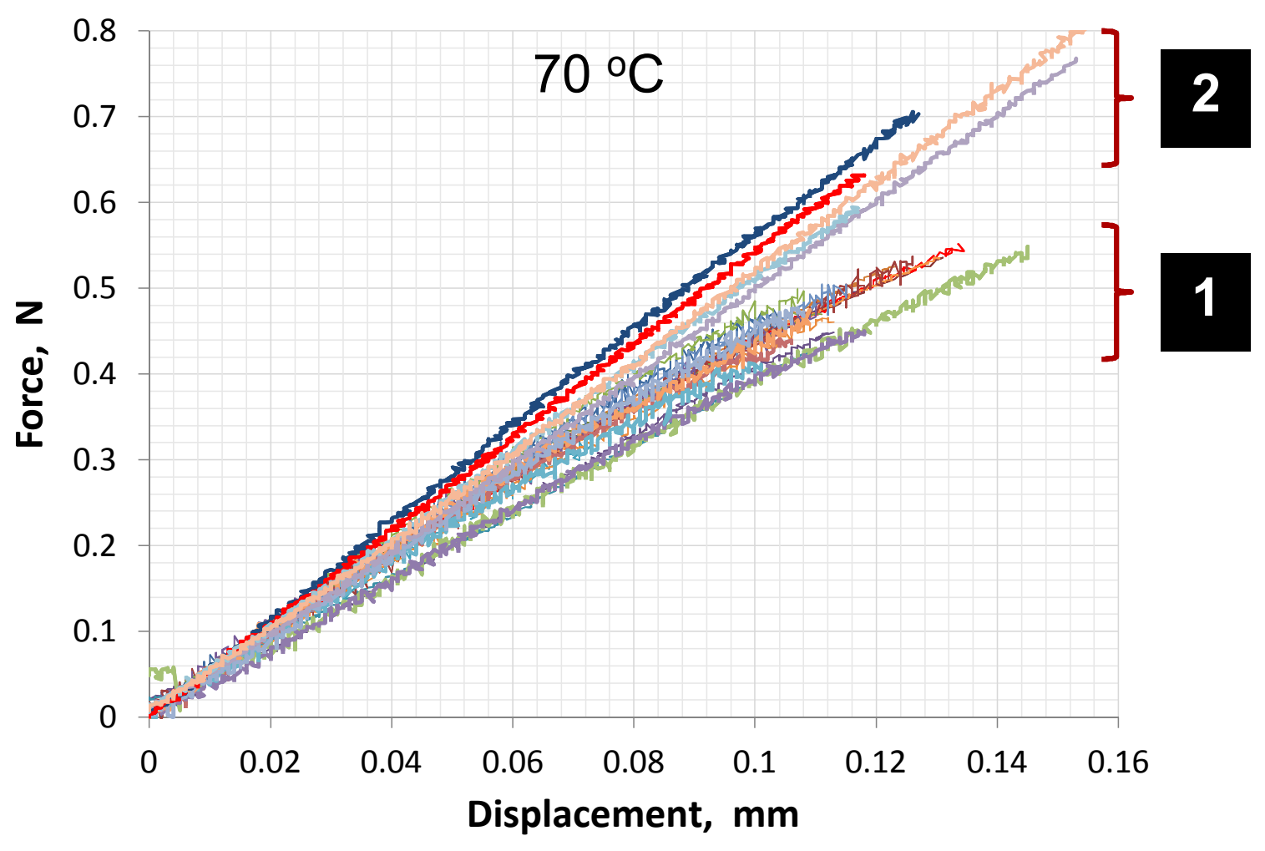


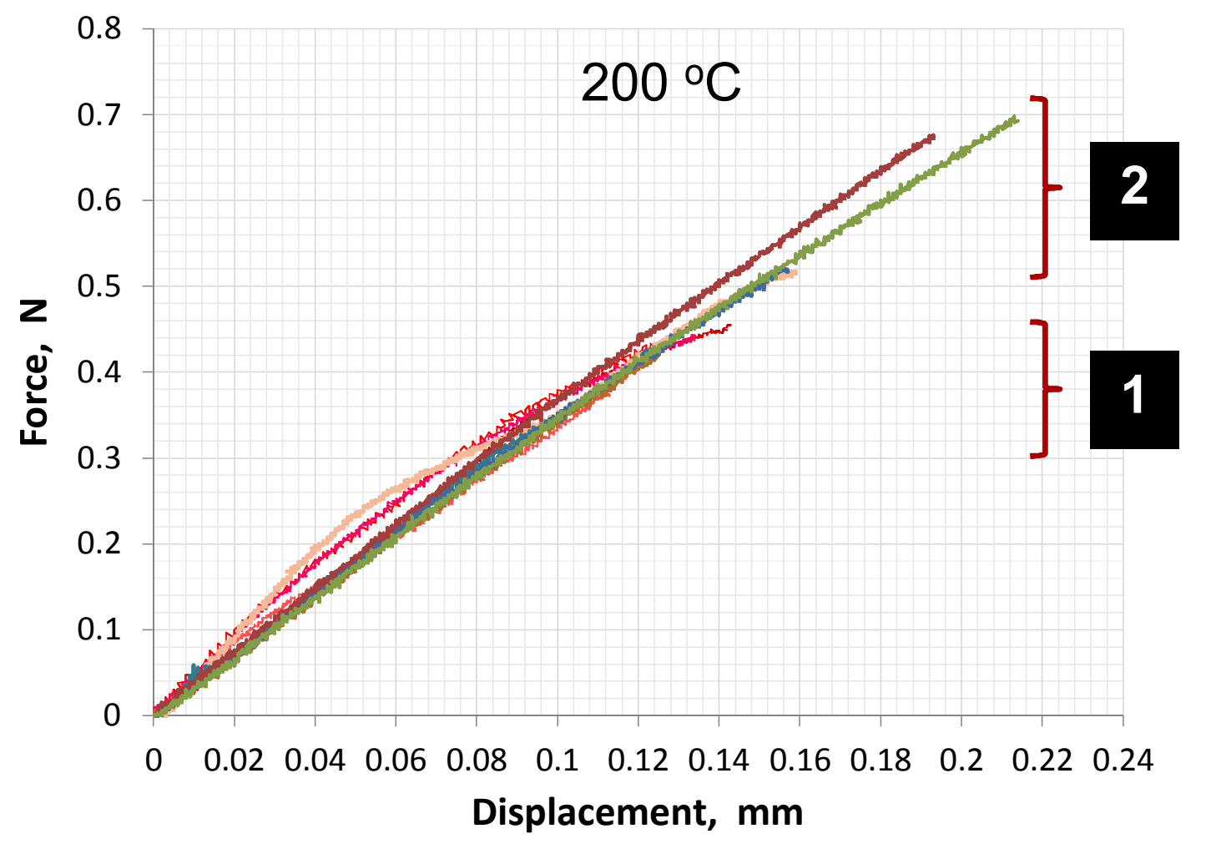


## Experimental Results

- Load – displacement curves

N-Type





- P-Type has the similar trend

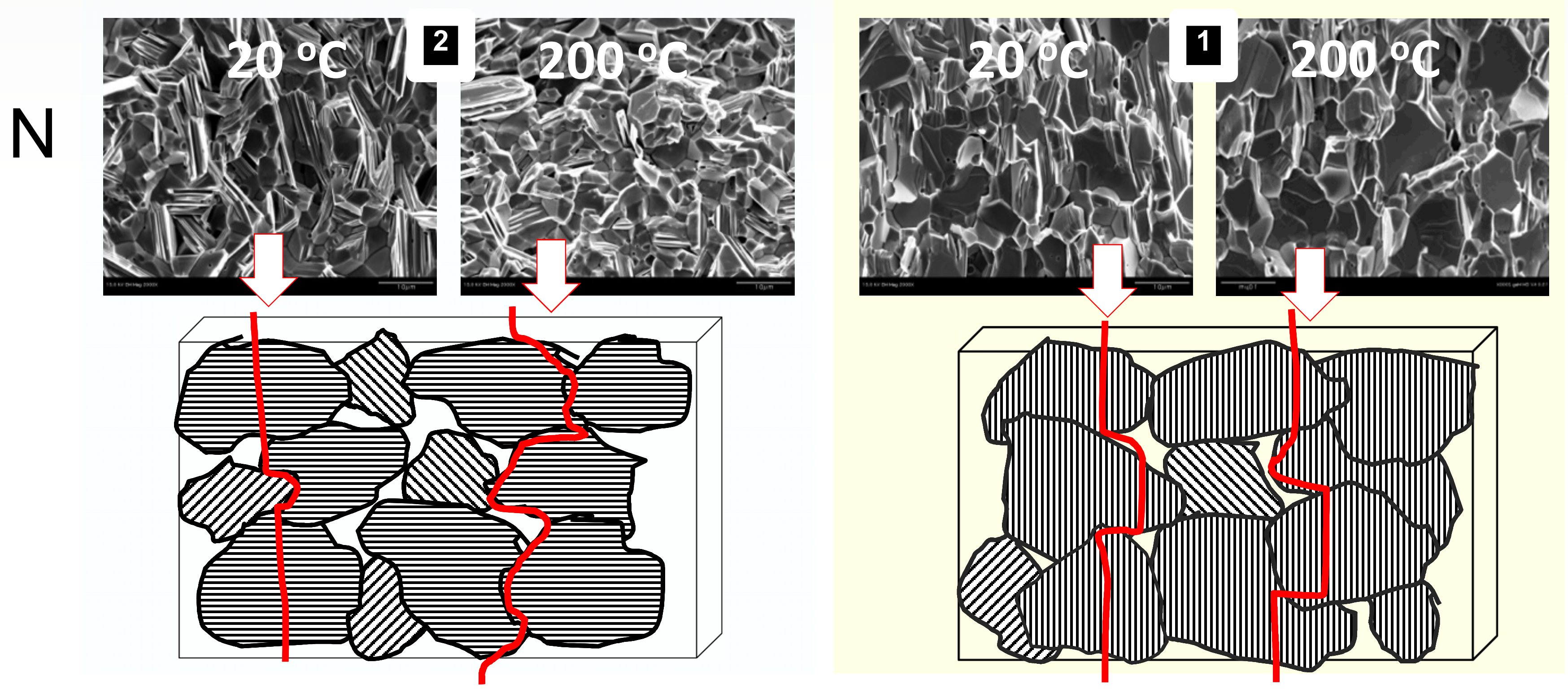
## Experimental Results (continued)

- Modulus ($E$) and Strength ($\sigma_{max}$)

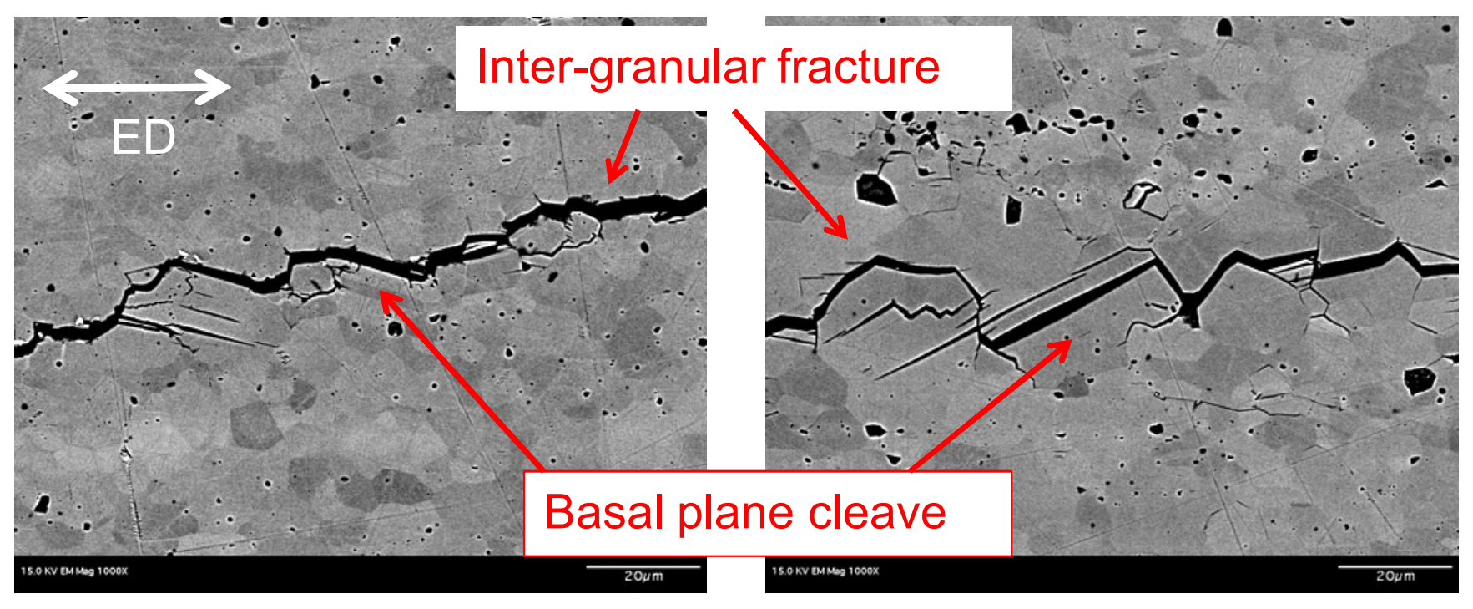
| Specimen | $T$ = 20 °C | | $T$ = 200 °C | |
|---|---|---|---|---|
| | $E$ (GPa) | $\sigma_{max}$ (GPa) | $E$ (GPa) | $\sigma_{max}$ (GPa) |
| N 1 | 34.9 | 60.0 | 32.0 | 59.7 |
| N 2 | 38.5 | 88.6 | 26.8 | 67.3 |
| P 1 | 24.8 | 44.5 | 23.7 | 48.1 |
| P 2 | 35.8 | 86.4 | 25.9 | 70.5 |

## Failure Mechanism

- Group 1 samples, brittle basal cleavage mixed-in with inter-granular fracture, along the ED direction
- Group 2, trans-granular fracture, perpendicular to the ED direction; changes to inter-granular at 200 °C

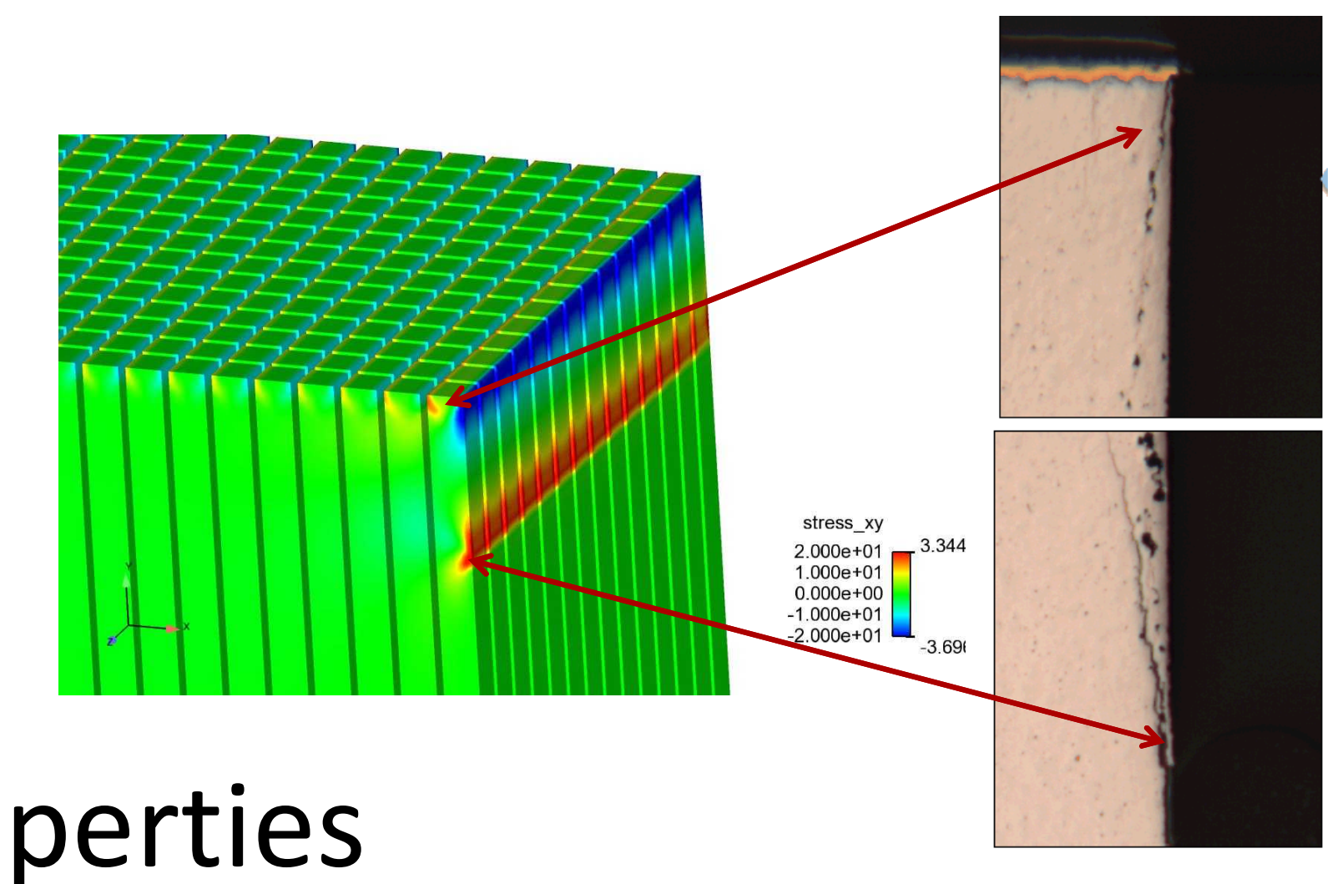


- Group 1 sample failure mechanisms are observed in finished TE modules



## Summary

- Mechanical properties of $Bi_2Te_3$-based alloys are dependent on crystal orientation and temperature
- The materials are brittle and susceptible to manufacture-induced stress cracking
- Optimization to minimize the residual stresses is necessary to mitigate the vulnerability of mechanical failure
- The measured mechanical properties are currently being used in computer simulations of fabrication processes and operational environments



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