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Encapsulation of High Temperature Thermoelectric Modules

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Advanced Power and Energy Systems

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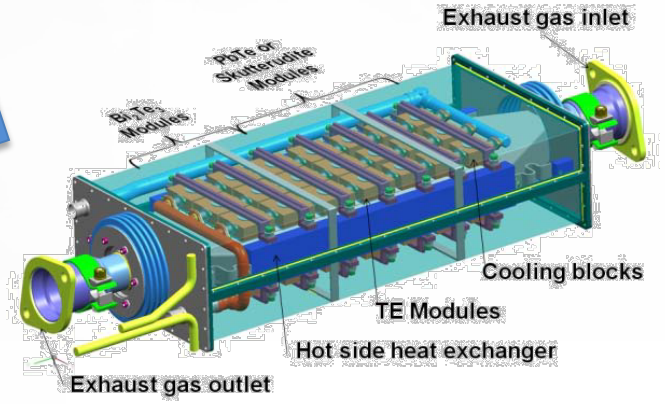
Introduction

Problem Description

- Skutterudite materials are highly susceptible to oxidation
- Oxide is not self limiting. Materials degrade quickly in air at operating temps
- System level barriers are currently employed to prevent oxidation

J. Salvador and G. Meisner, DEER, 2011.



G. Meisner, TE App Workshop, 2011.

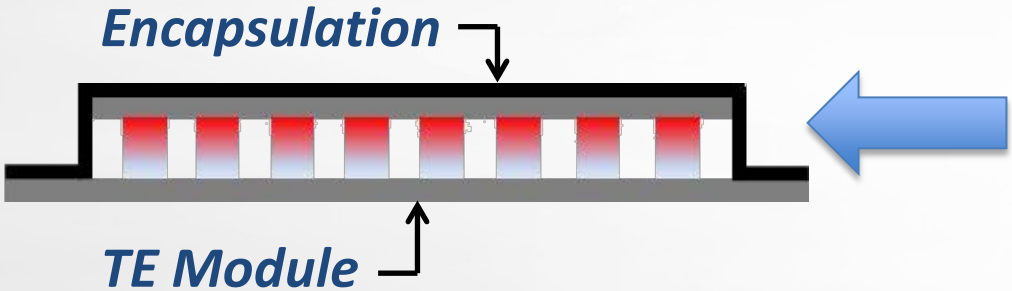
Goal

- Develop module level encapsulation to enable long term durability of TE materials
- Most applicable to system architectures using a traditional module geometry

Module Encapsulation

Advantages

- Enables redundancy or elimination of system enclosure
- Hermeticity of system level enclosure is not required
- Offers system level design flexibility
- Hermetic barrier not exposed to harsh environment
- System maintenance would not disrupt critical seal
- Potential for reduced system cost
- May reduce thermal shunting

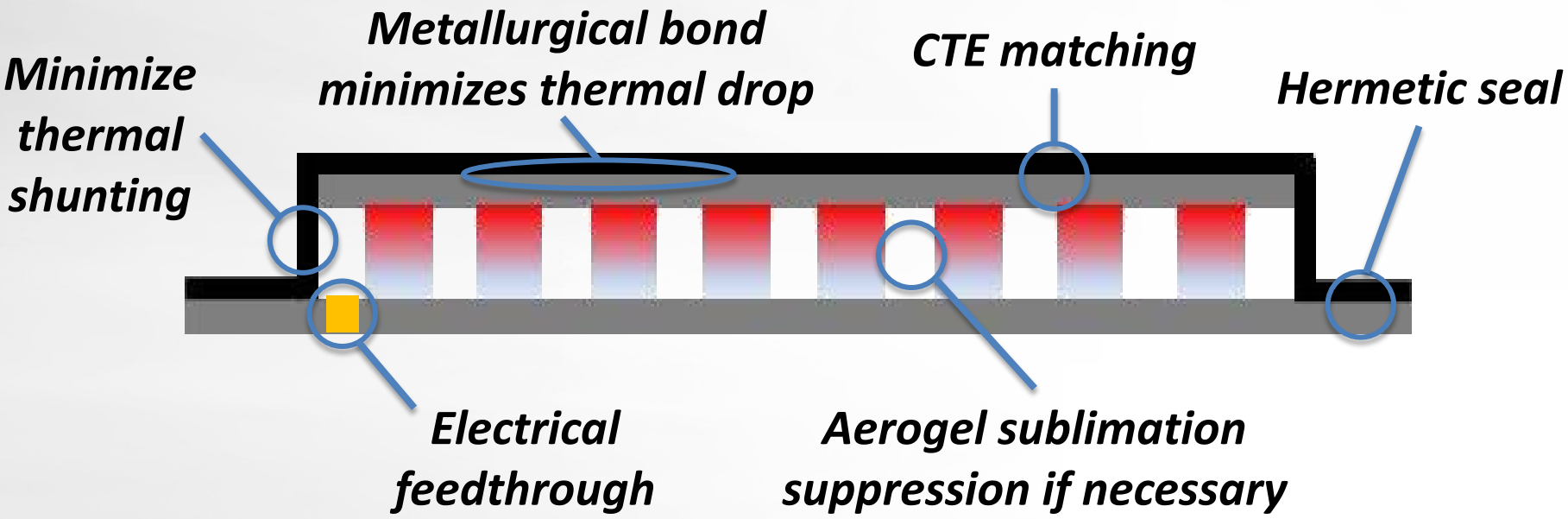


G. Meisner, TE App Workshop, 2011.

Module Encapsulation

Design Considerations

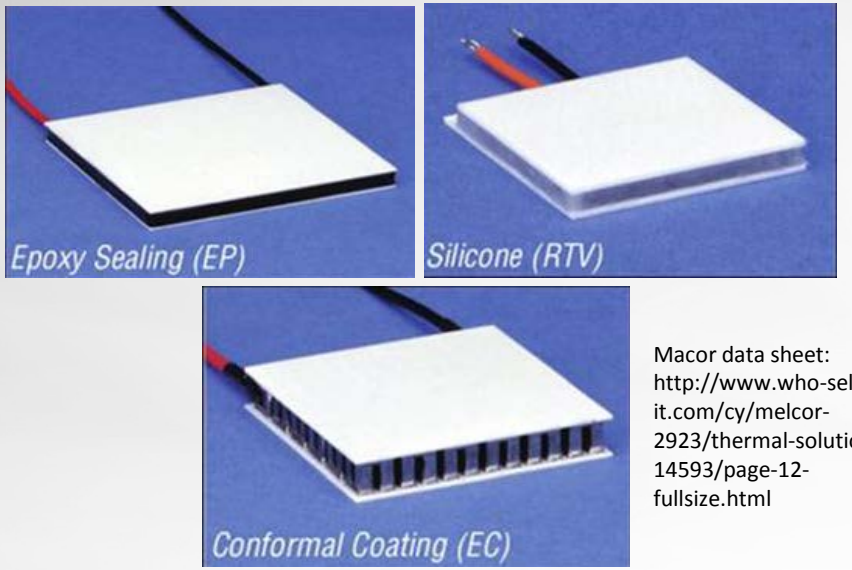
- Encapsulate modules after assembly
- Operate continuously at T_{hot}=500°C
- Manufacturable and low cost



Encapsulation Approaches

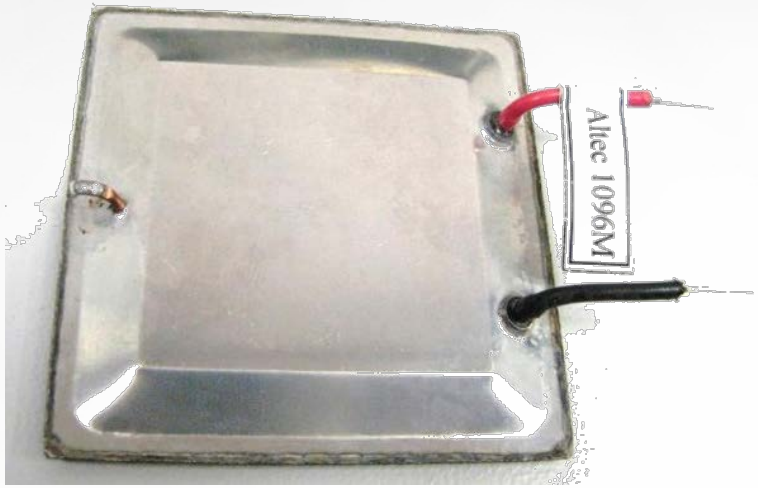
Low temperature moisture barriers

Polymer Coatings



Macor data sheet: http://www.who-sells-it.com/cy/melcor-2923/thermal-solutions-14593/page-12-fullsize.html

Metal Enclosure



Altec 1096M Thermoelectric Module
Photo courtesy of Pawan Gogna, JPL

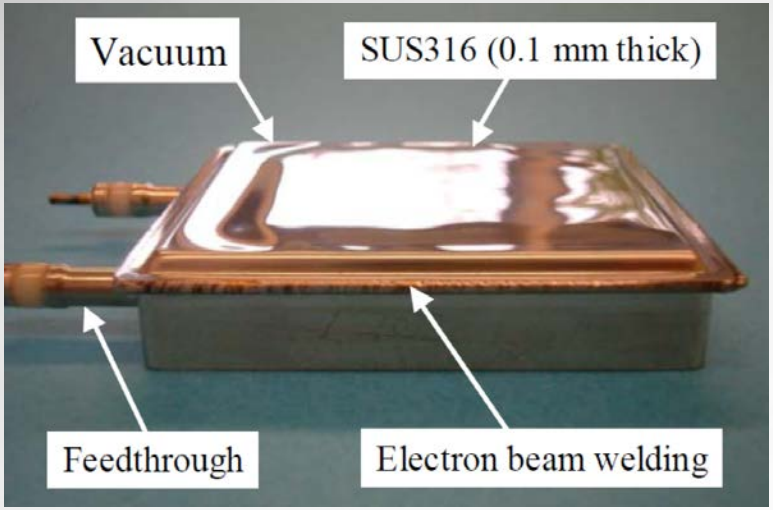
- Oxidation of BiTe not an issue < 250°C
- Polymer not suitable at T_{hot} = 500°C
- Hermeticity of coatings not testable by leak testing

- Organic feedthrough is not hermetic
- Mechanical interface between metal enclosure and ceramic plates
- CTE of SS does not match ceramic

Encapsulation Approaches

High temperature concepts

Metal Enclosure



M. Kambe, et al., J of Elec and Mtrl, 2010

- Tested SiGe modules to T_{hot} = 550°C
- Machined SS container
- Bulky housing and feedthroughs
- E-beam welding
- Mechanical thermal interfaces

Coatings

J. Paik, et al., NASA JPL Presentation.

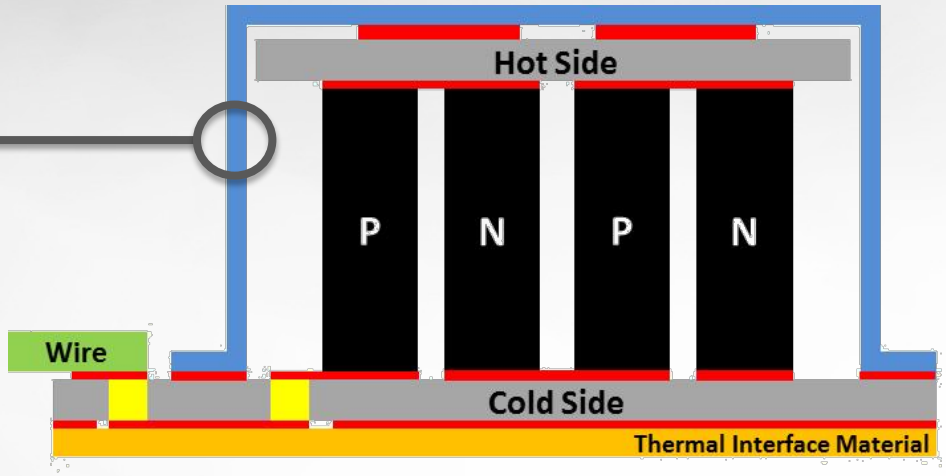
- Aerogel for sublimation suppression
  - Use in combination with encapsulation
- Barrier coatings
  - Use as hermetic barrier is challenging
  - Crack or delam opens oxidation path

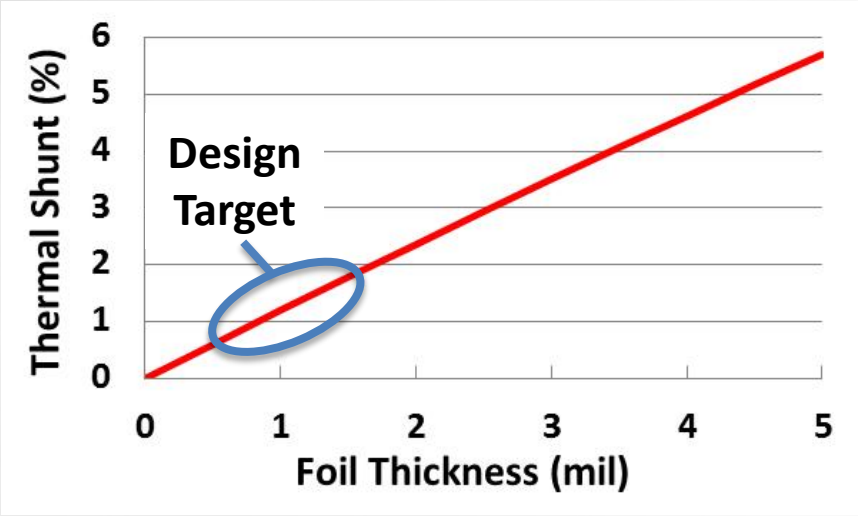
Encapsulation Concept

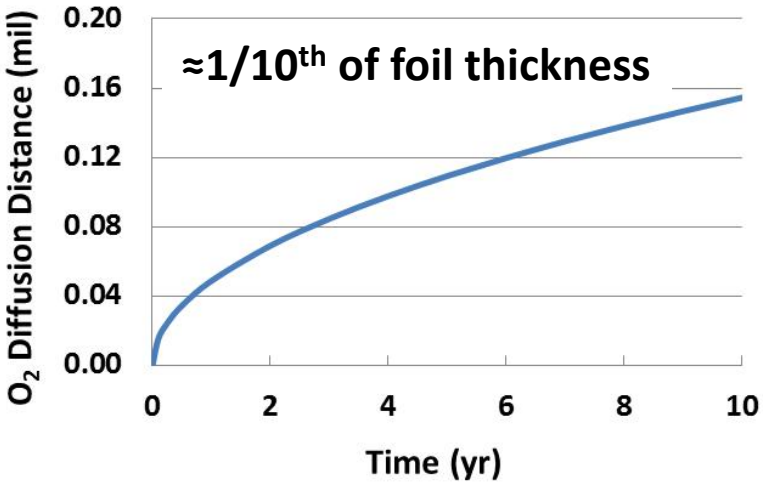
Key Design Features

1. Metal Cap

Metal foil with CTE of ceramic
Thermal shunting <2% of total heat flow
Oxygen diffusion depth << foil thickness
Concepts to further reduce shunting





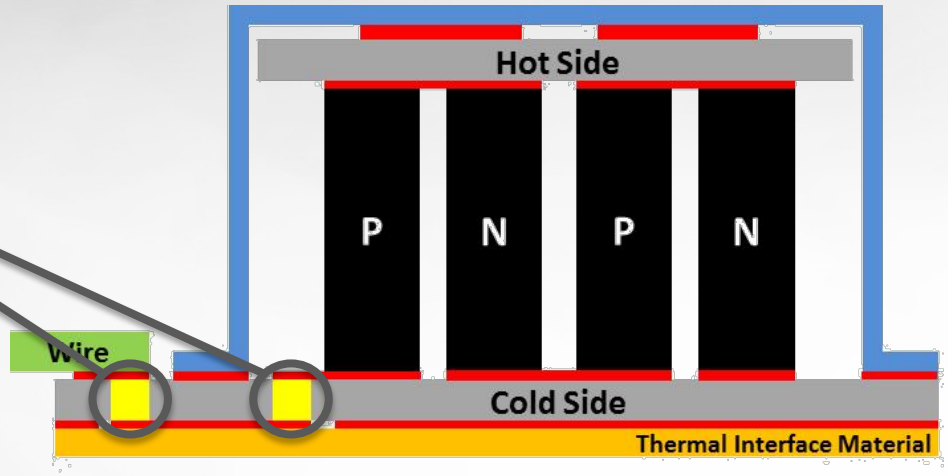


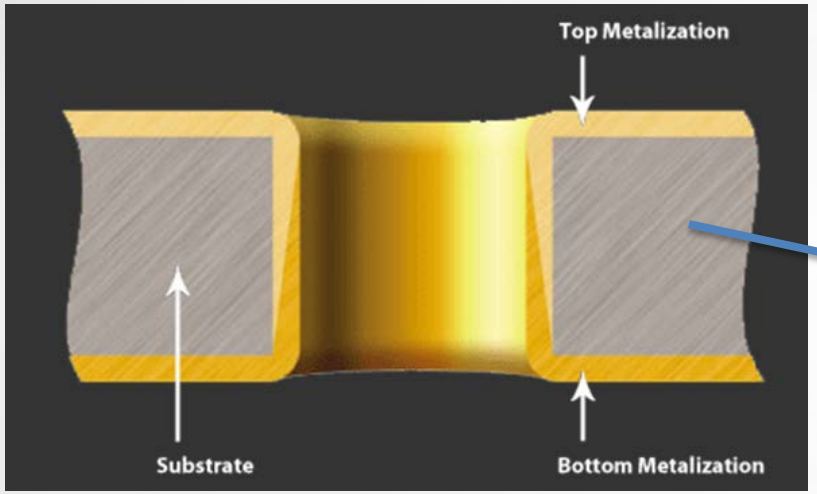
Encapsulation Concept

Key Design Features

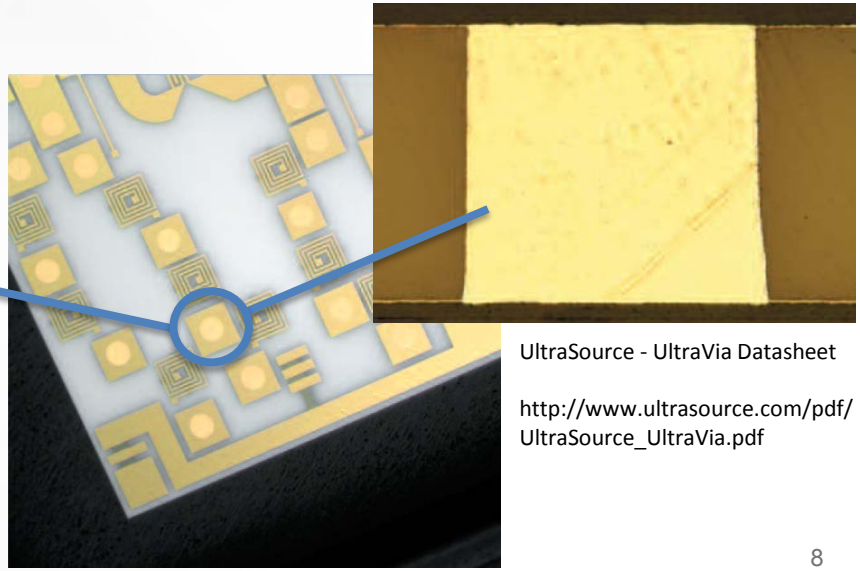
2. Conductive Vias

Metallic vias through ceramic
Thickness up to 1mm
Diameter up to 0.5mm
Low resistance ≈ 0.1mΩ





http://www.ultrasource.com/ultravianew.html



UltraSource - UltraVia Datasheet

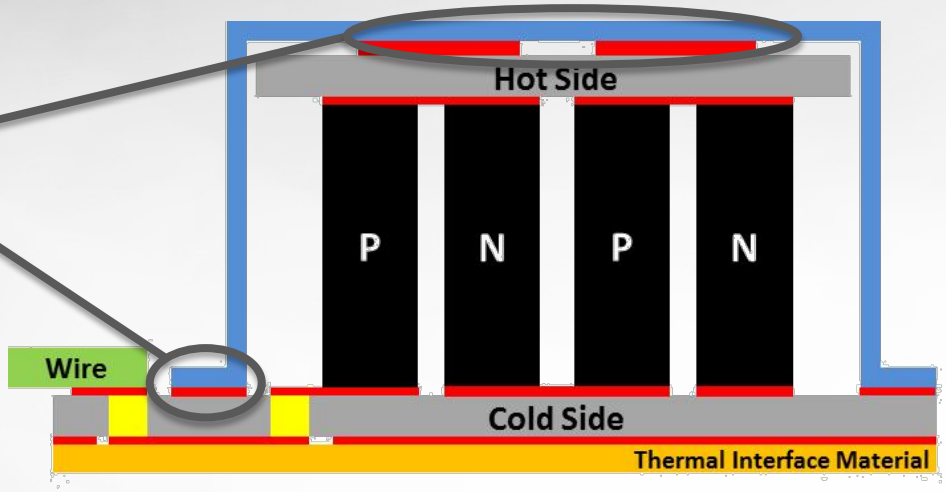
http://www.ultrasource.com/pdf/UltraSource_UltraVia.pdf

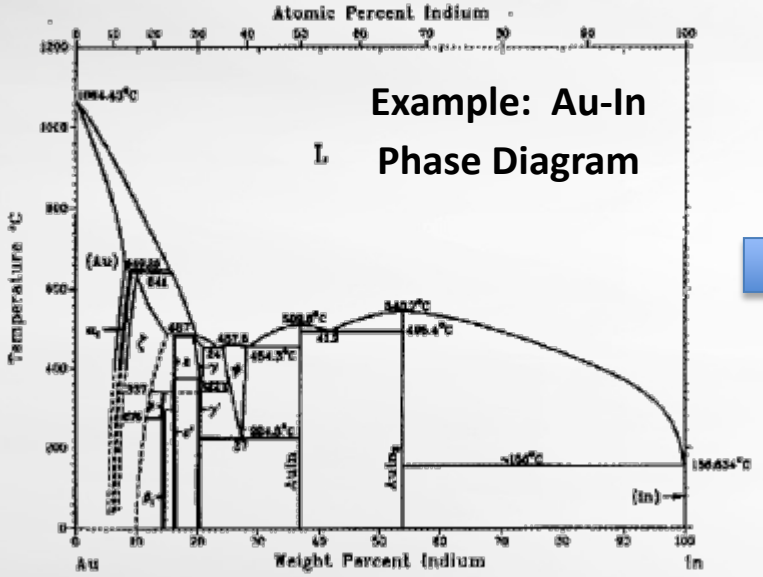
Encapsulation Concept

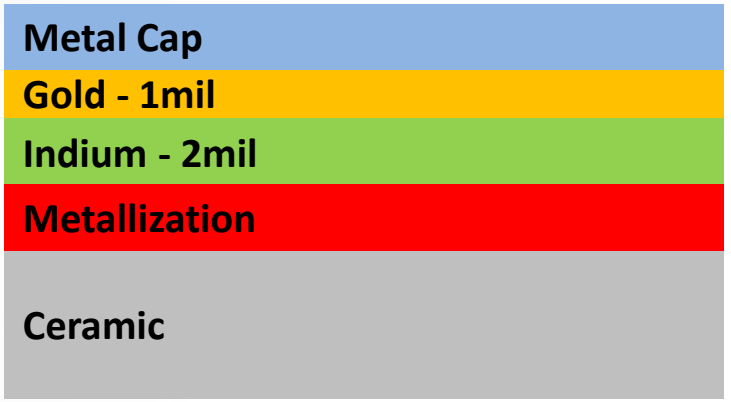
Key Design Features

3. Metallurgical Bonds

Minimize interface thermal impedance
Must be stable above hot side temp
Transient Liquid Phase Bond (TLP)
- *Process at low temp, re-melt at high*
- *Flux-less process*







Summary

- Skutterudite materials are susceptible to oxidation
- Module level encapsulation prevents oxidation
- Advantages
  - Redundancy for improved reliability
  - Eliminate system level enclosure
  - System level design flexibility
  - Potential for reduced cost and thermal shunting

G. Meisner, TE App Workshop, 2011.