

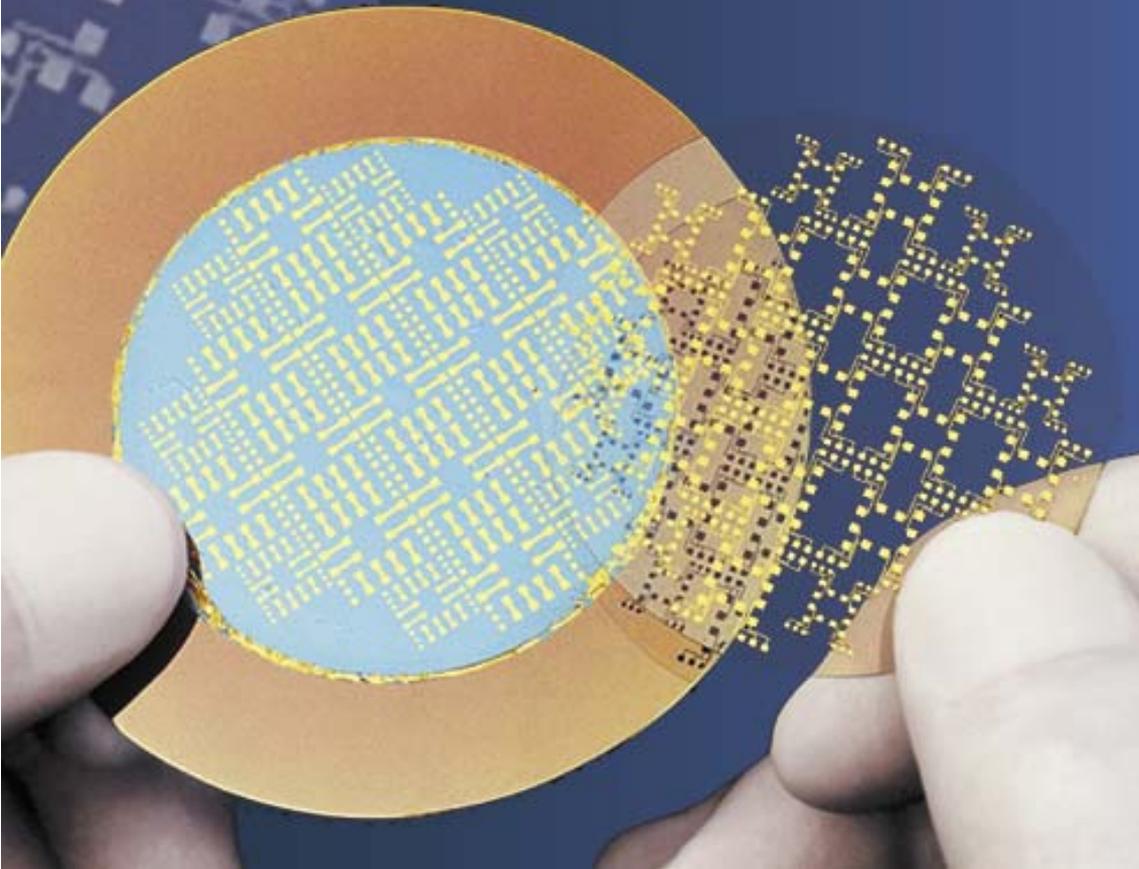
Nano-structured Thermoelectric Materials

8th Diesel Engine Emissions Reduction Conference

Loews Coronado Bay Resort

San Diego, CA

August 25, 2002



Rama Venkatasubramanian

RTI
INTERNATIONAL

Outline

- Introduction – Relevance to CFC-free Air-conditioning in Automobiles, Energy Conservation and Emissions Reduction
- Advantages of Technology and Thin-film Cooling Examples
- Thin-film Power Conversion Examples
- Major Outstanding Issues for Research
- Emerging Thin-film TE Technology Applications

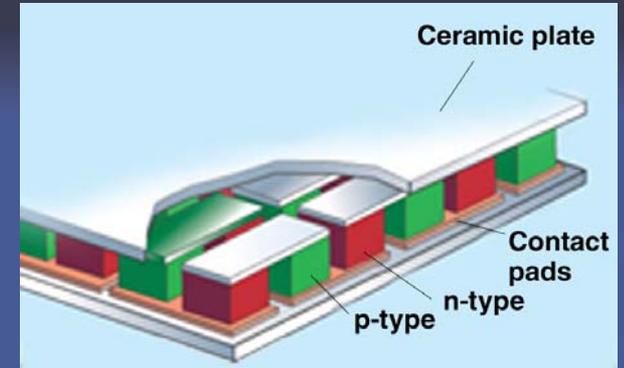
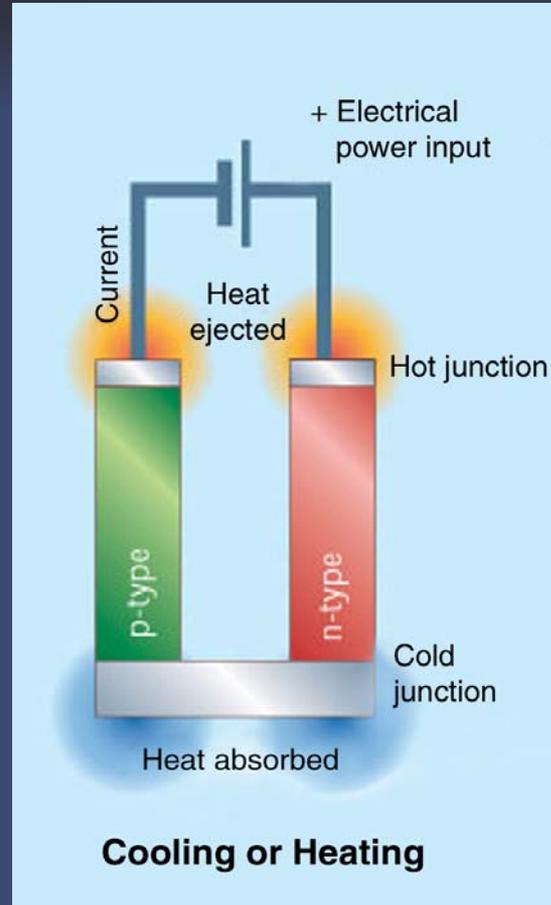
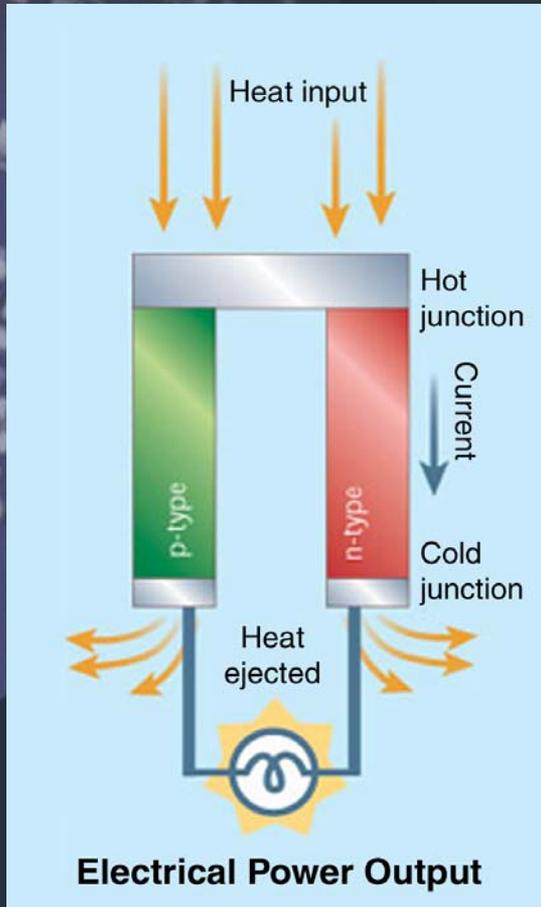
Why Thermoelectrics?

- Converts electrical and thermal energy using a solid state device with minimal moving parts
- **Chip-scale functionality** with thin-film materials using standard microelectronic processing
 - Computer Chip, Photonic Chip, Lab-on-a-Chip
- Green Technology – CFC-free refrigeration to waste-heat recovery for fuel efficiency



Christine Cox / MSNBC

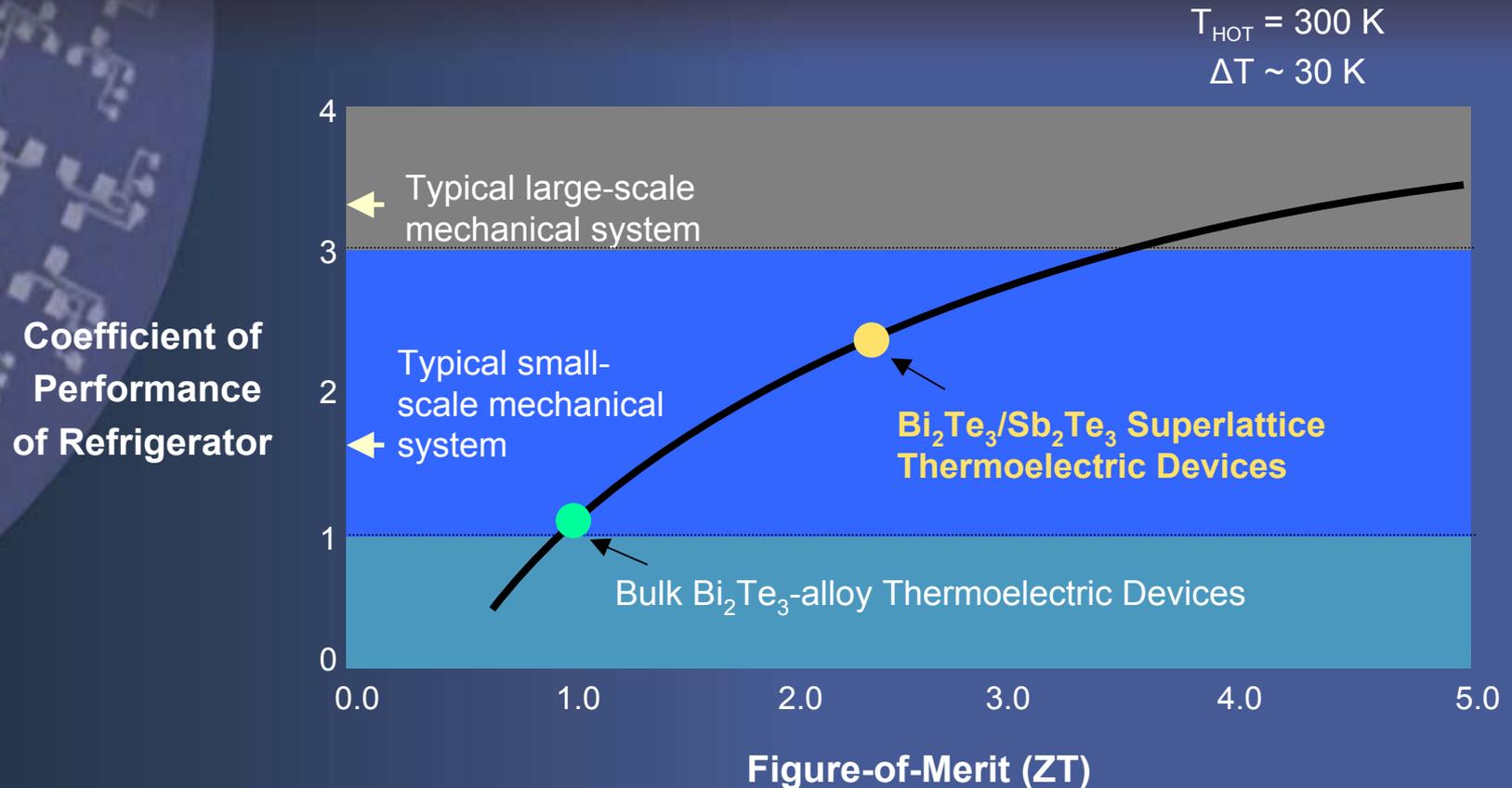
Thermoelectric Effect



- Cooling or Power Conversion Efficiency critically dependent on the material Figure of Merit (ZT)
- $ZT = (\alpha^2\sigma/K)T$
- Minimize thermal conductivity and maximize electrical conductivity

Ref : Nature, 413, 577 (2001)

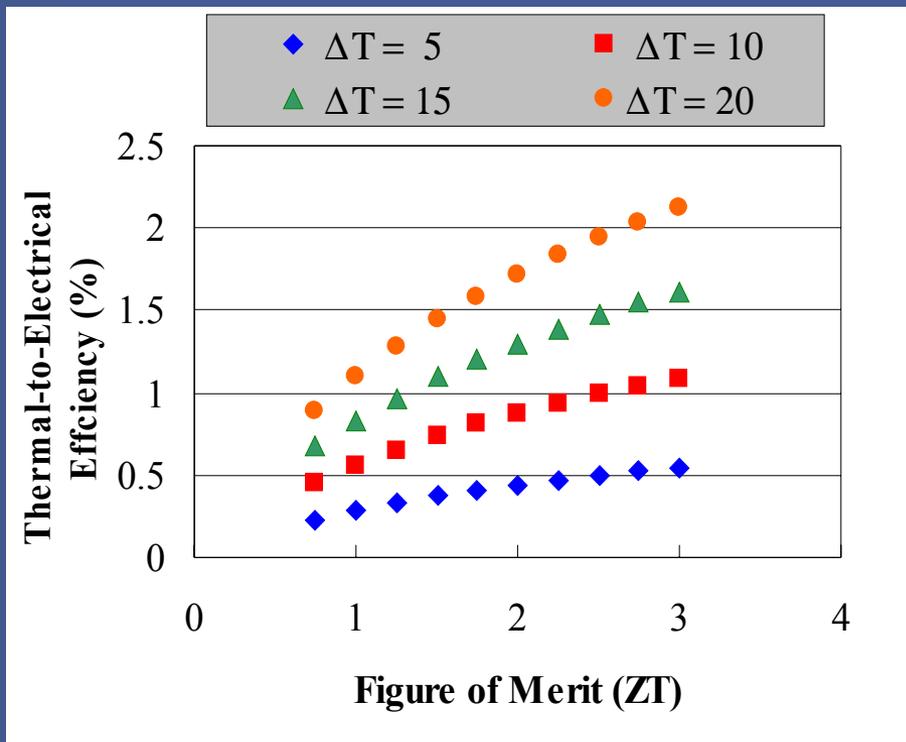
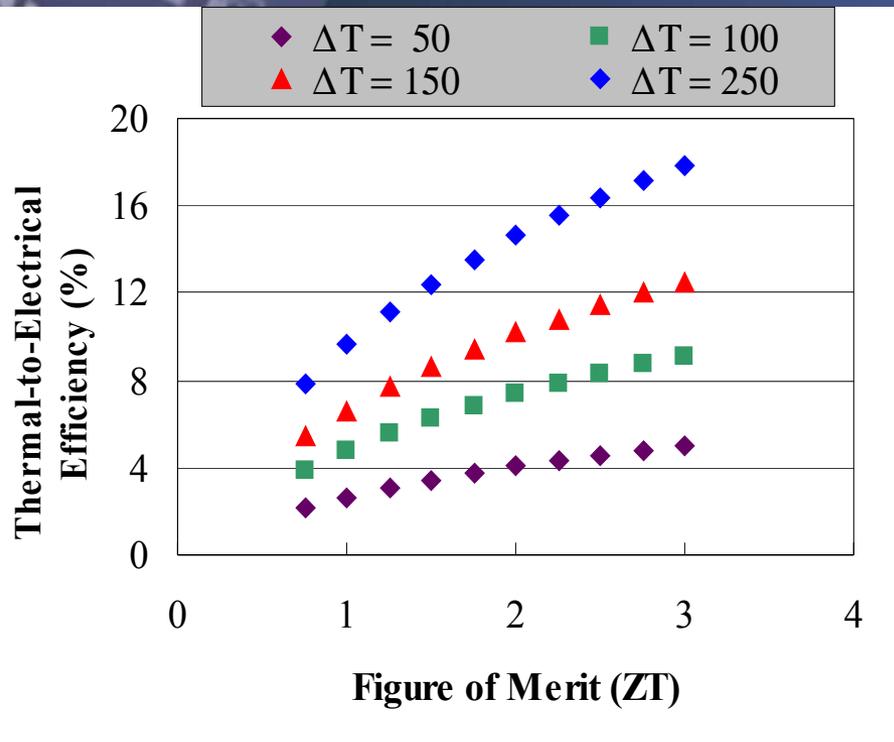
ZT and COP of Refrigerator or Air-Conditioner



Higher ZT – Incentives for New Approaches to Implementing Higher COP Concepts

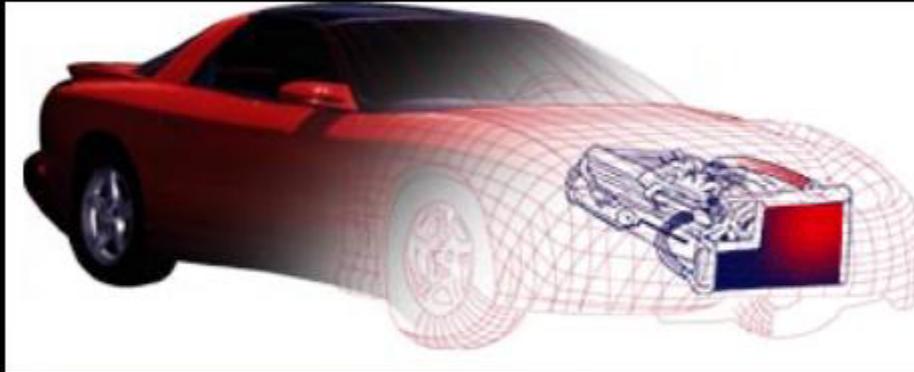
Implications for Power

- High-density, light-weight
- Higher efficiency
- Replace Batteries

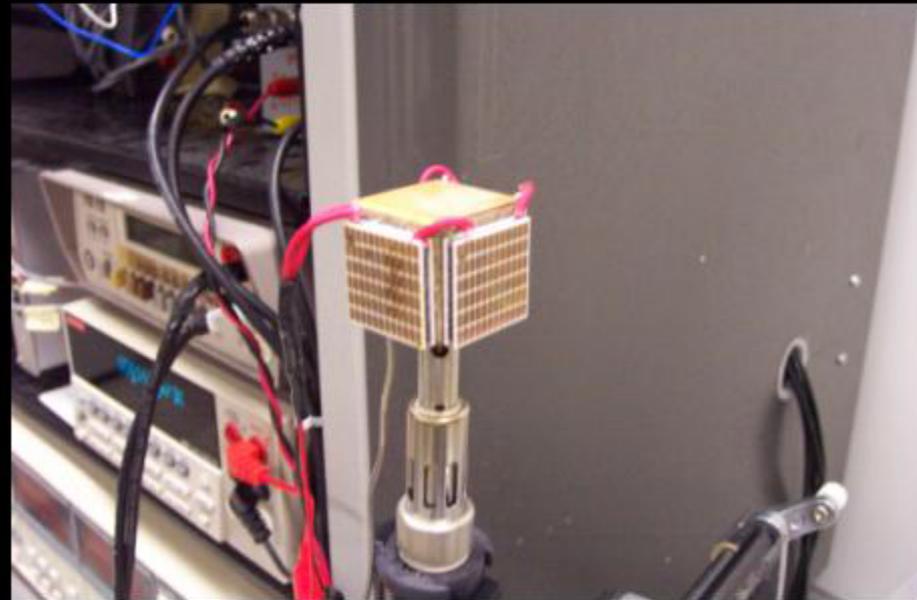


Automotive Power

Waste-heat recovery for electrical power



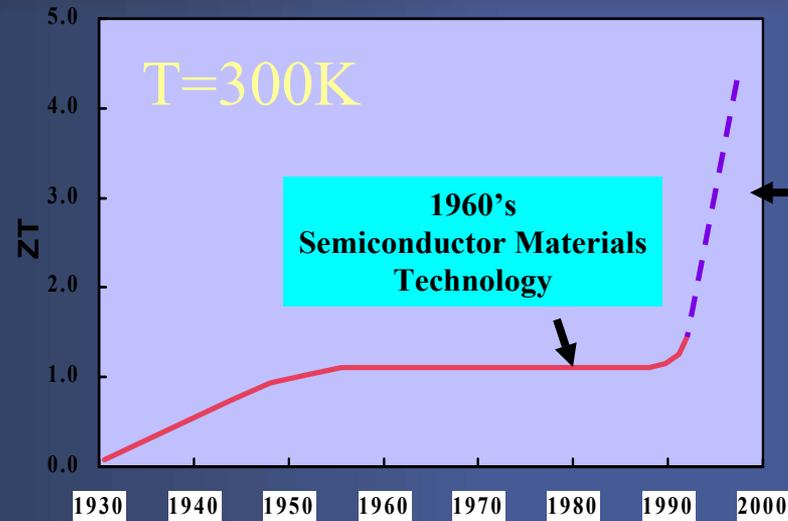
Portable power



Thermal scavenging
for remote power

THERMOELECTRIC TECHNOLOGIES in 1992

Fort Belvoir Workshop Organized by Dr. Stuart Horn



- ZT - figure of merit - has been stagnant at about 0.8 to 1 for the last 40 years - cooling and power conversion efficiencies low - useful only in applications where you really need it
- ZT need to improve over 1.5 at 300K for a major impact in electronics and around 2 to 2.5 for a revolutionary impact in air-conditioning, and power from waste-heat

Some of the Bulk Material and Thin-film Developments

- ◆ Cs Bi₄Te₆ (Michigan State University)
 - Bulk Materials with a ZT~ 0.8 at 225K but less than 0.8 at 300K (*Science* **287**, 1024-1027, 2000)
- ◆ Filled Skuterrudites (JPL)
 - Bulk materials with a ZT ~1.35 at 900K (Proc. Of 15th International Conf. On Thermoelectrics, 1996)
- ◆ PbTe/PbTeSe Quantum-dots (MIT Lincoln Labs.)
 - ZT~2 at 550K and ZT~0.8 at 300K based on estimated thermal conductivity values (J. Electronic Materials, 29, L1 , 2000)
- ◆ Bi₂Te₃/Sb₂Te₃ Superlattices (RTI)
 - ZT~2.4 at 300K in devices with all properties measured at the same place, same time, with current flowing and verified by two independent techniques (*Nature*, 597-602, 2001)



Thermoelectrics
Research



Breakthrough
Nanotechnology

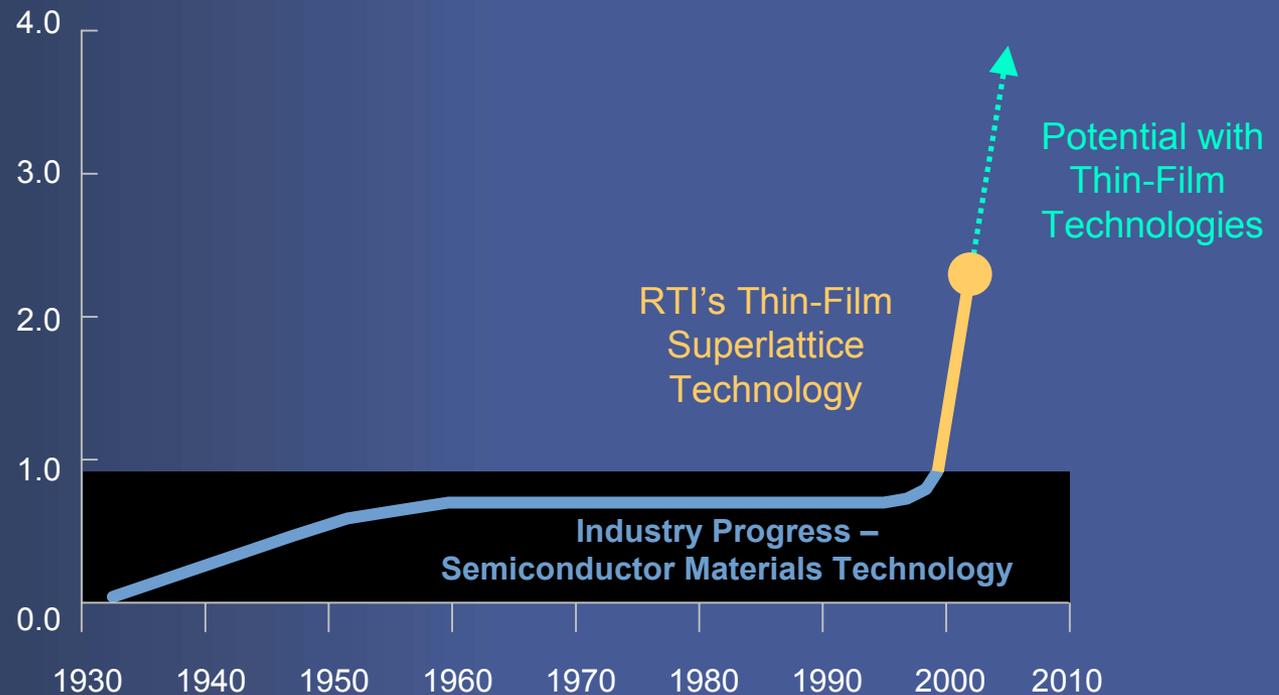


Multiple
Applications



RTI's 40-Year Breakthrough

Efficiency of
Thermoelectric
Material
(ZT)





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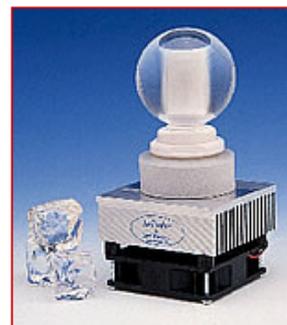
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Cool new film

Metal sandwiches can pump heat rapidly to or from chips.
11 October 2001

PHILIP BALL



New composite could shrink thermoelectric coolers like this one to the size of a chip.
© Coolworks, Inc.

A new composite could cool computer chips or warm scaled-down industrial chemical processing. It can pump heat rapidly to or from miniature devices.

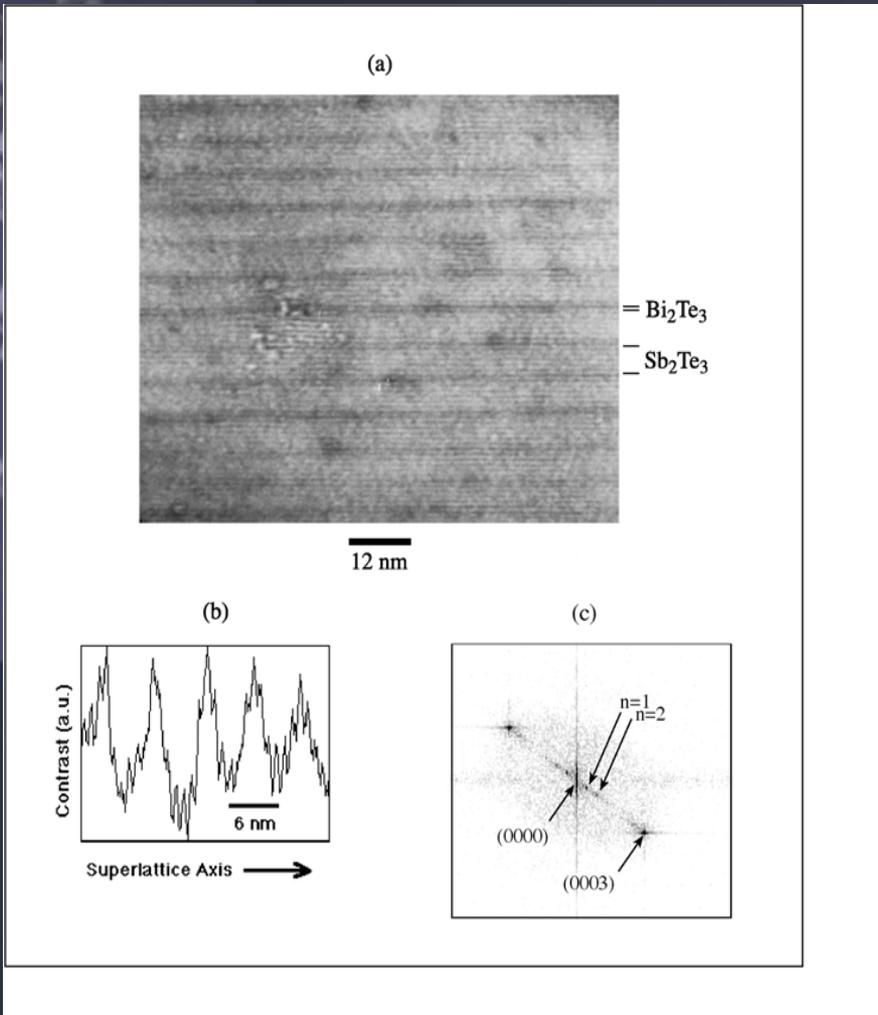
The material, devised by Rama Venkatasubramanian and colleagues at the Research Triangle Institute in North Carolina, relies on both aspects of the thermoelectric effect. The first aspect is that current is generated in two electrically conducting materials in contact when one is hotter than the other. The

- **Holes plug leaky circuits**
24 July 2001
- **Nothing to it**
22 May 2001
- **Glare hitch project**
12 April 2001
- **Cold chips shrink horizons**
16 March 2001

more news

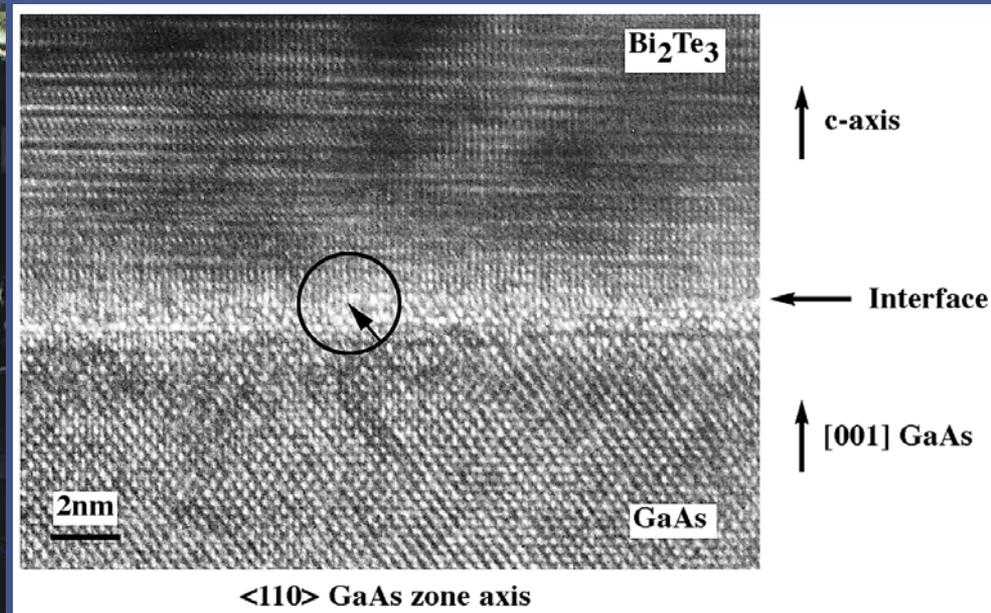
- **Sweat kills bugs**
5 November 2001
- **Letters from nowhere**
5 November 2001
- **Salt holds samples of ancient seas**
2 November 2001
- **Canaries change their tune**
2 November 2001

RTI's Nano-structured Superlattice Material



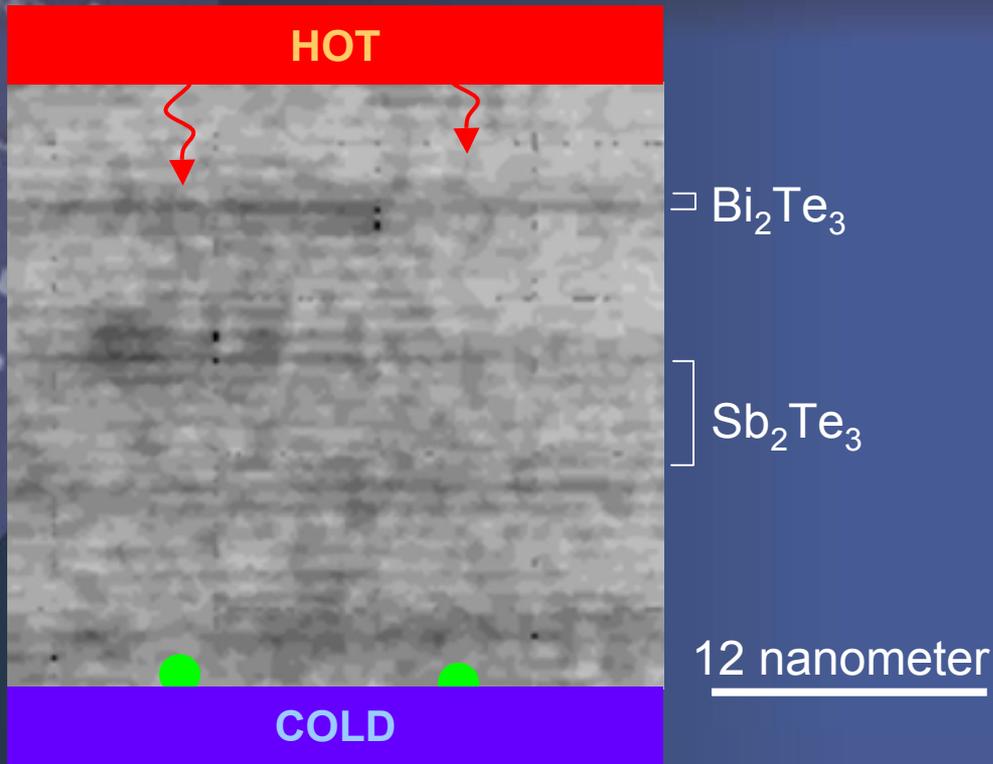
- 10Å/50Å $\text{Bi}_2\text{Te}_3/\text{Sb}_2\text{Te}_3$ Structure
- Optimized for disrupting heat transport while enhancing electron transport perpendicular to the superlattice interfaces

MOCVD Growth of Superlattices



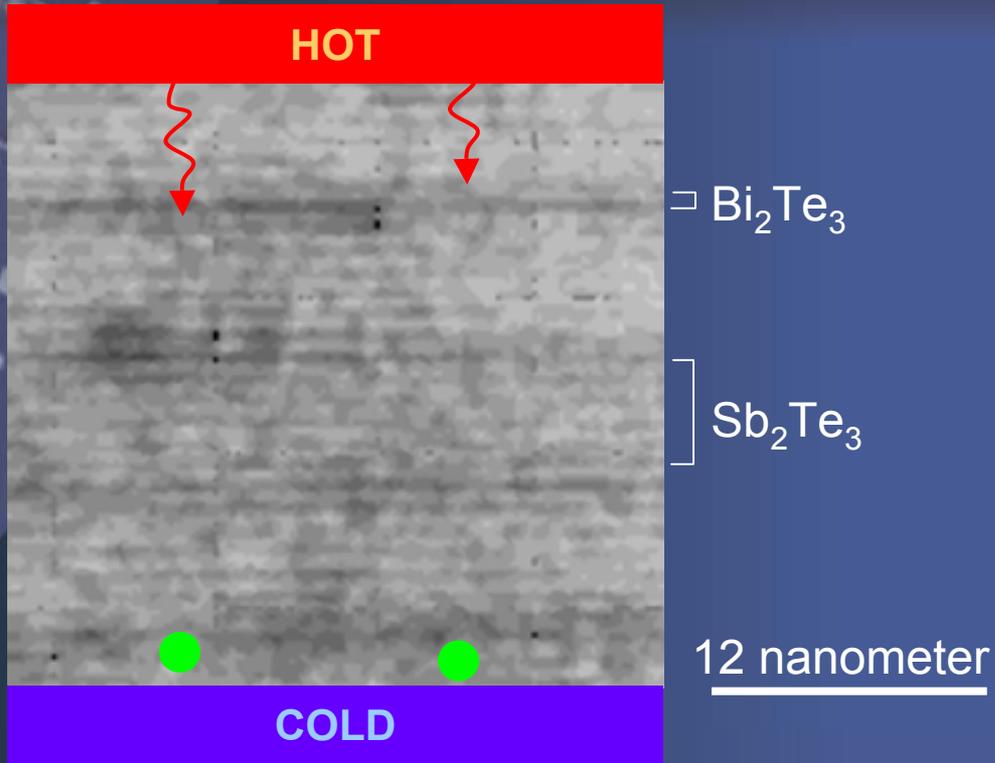
- Low-temperature technology and scaleable for large areas
- In-situ ellipsometry for nanometer-scale control of deposition

RTI's Superlattice Material



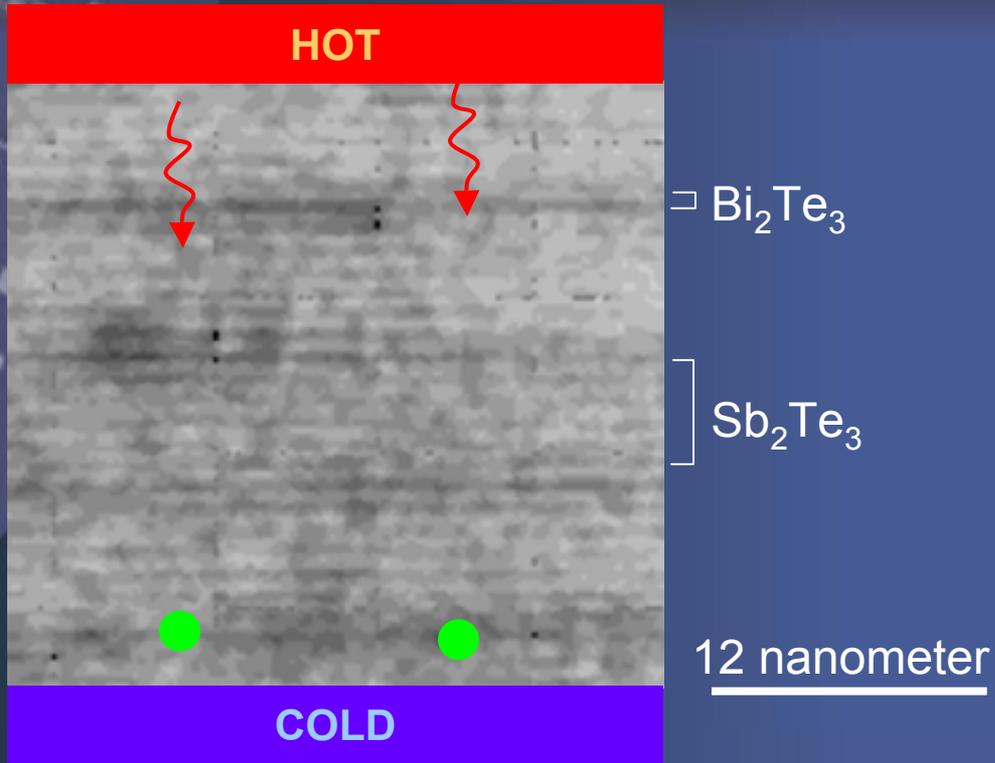
The RTI breakthrough arises from reducing heat transmission without disrupting electron flow

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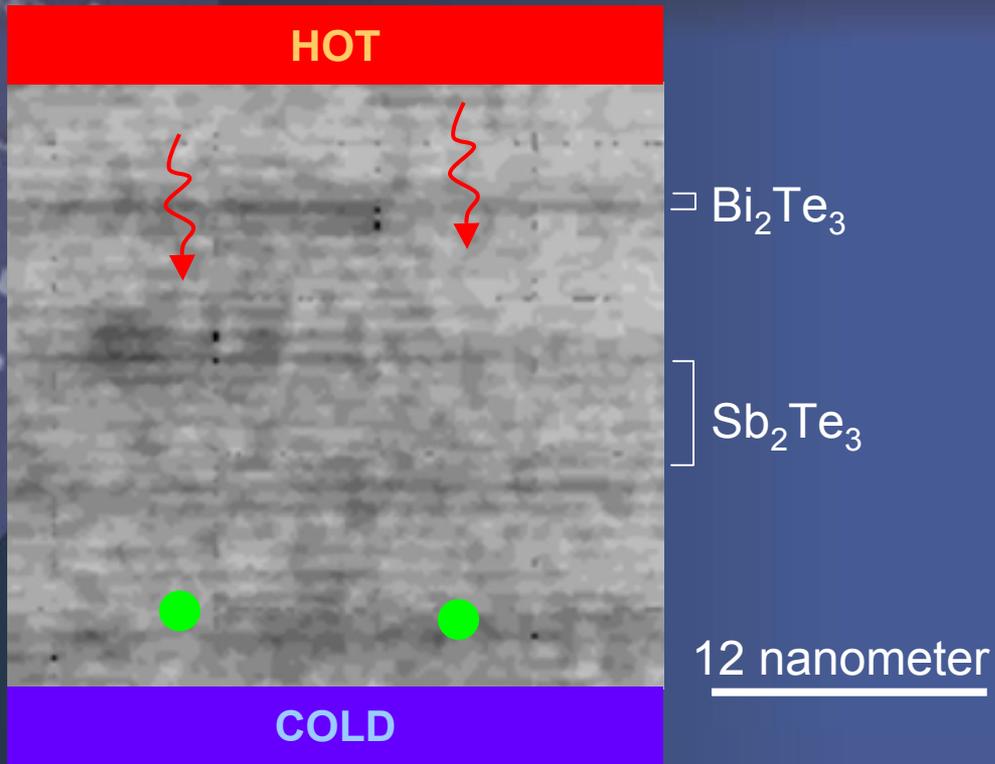
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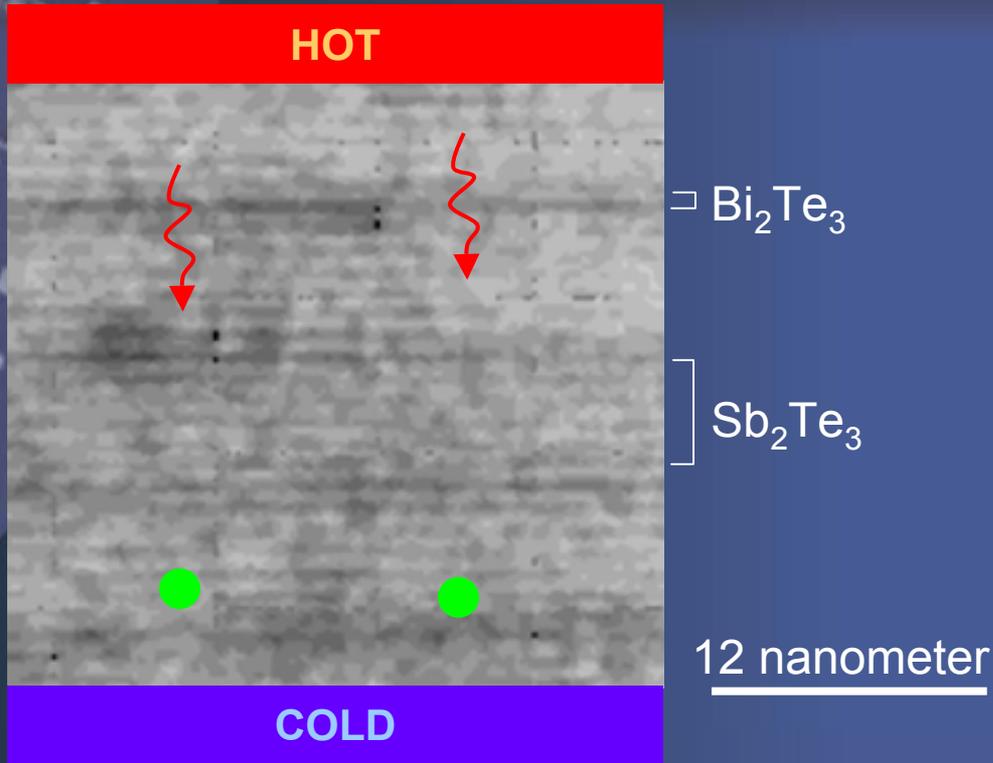
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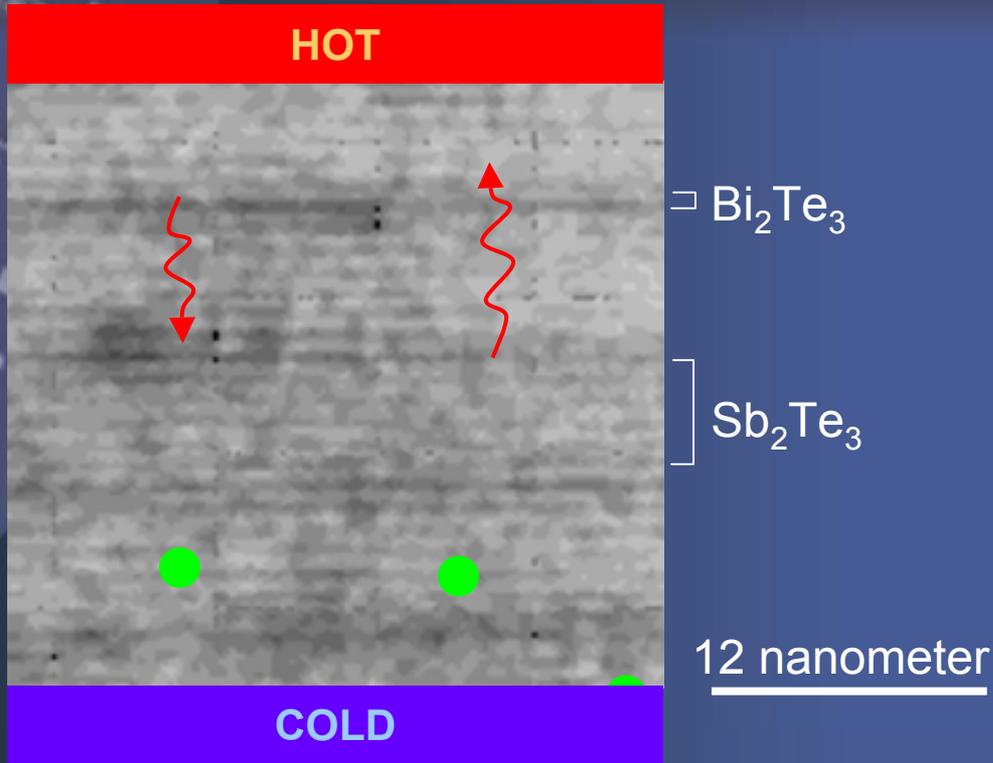
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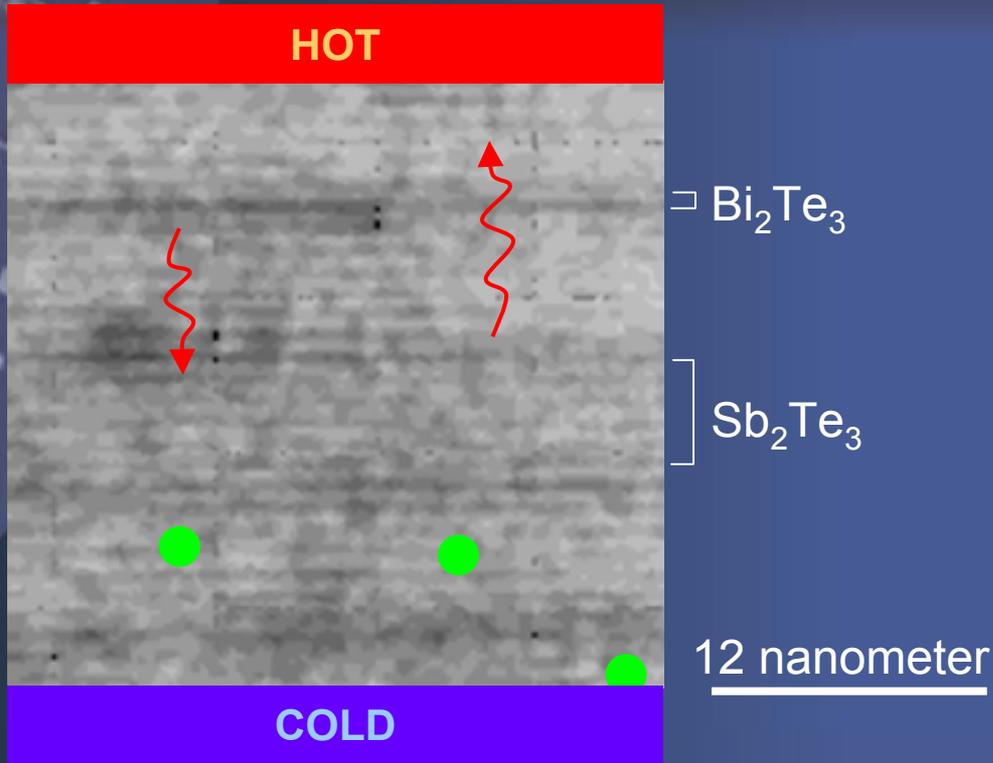
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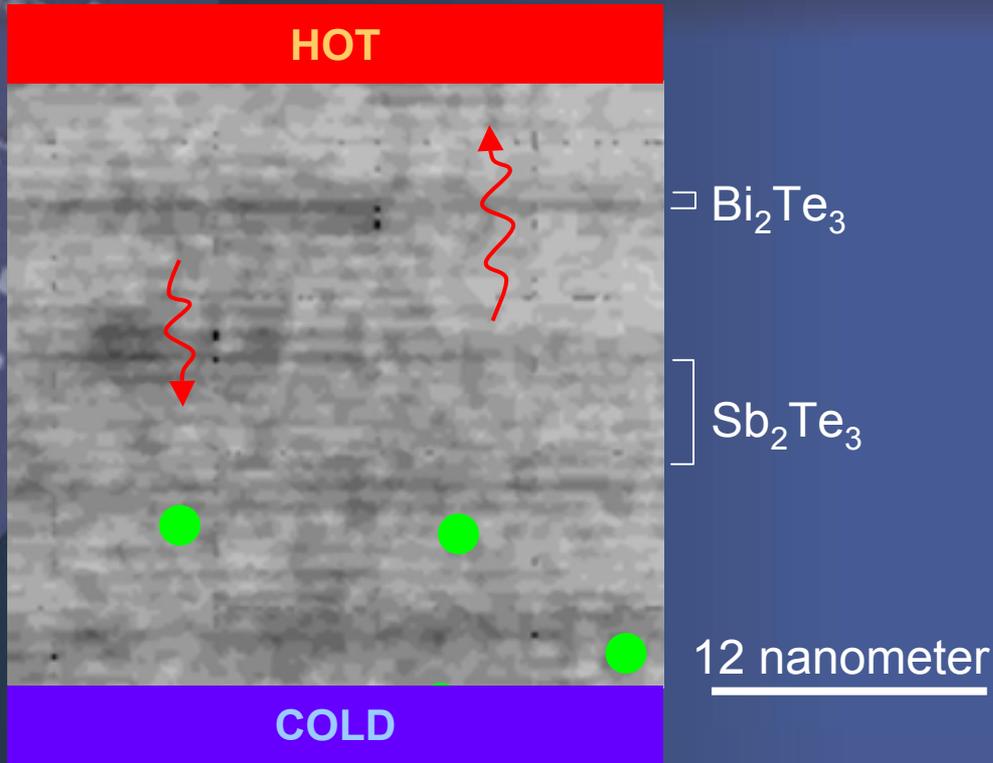
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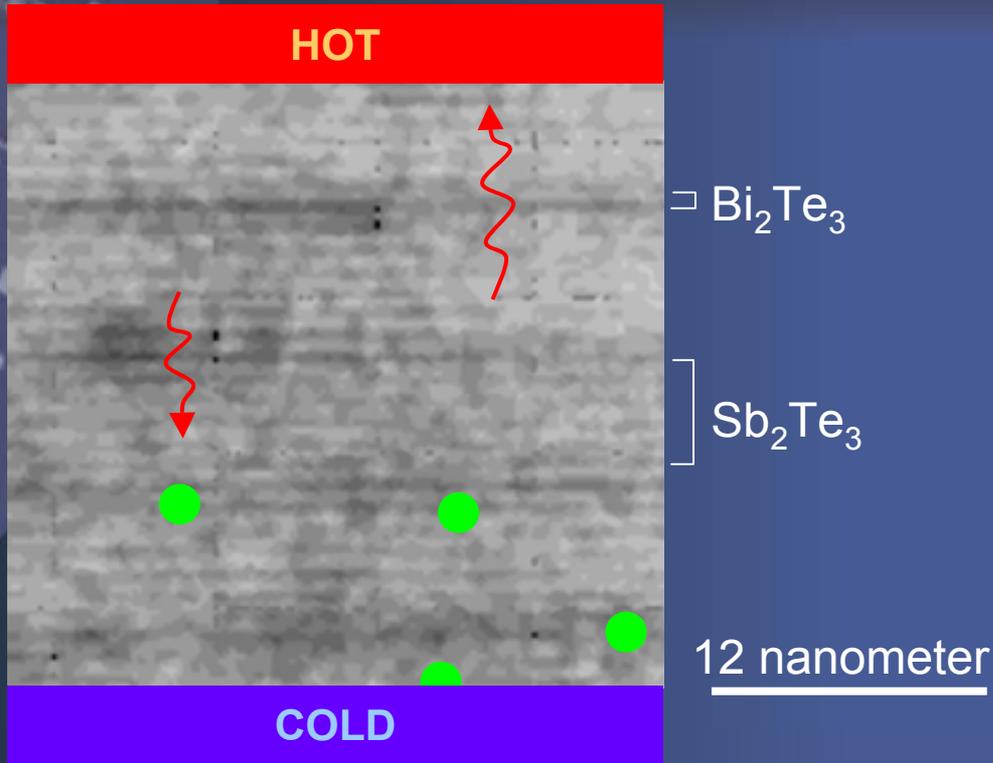
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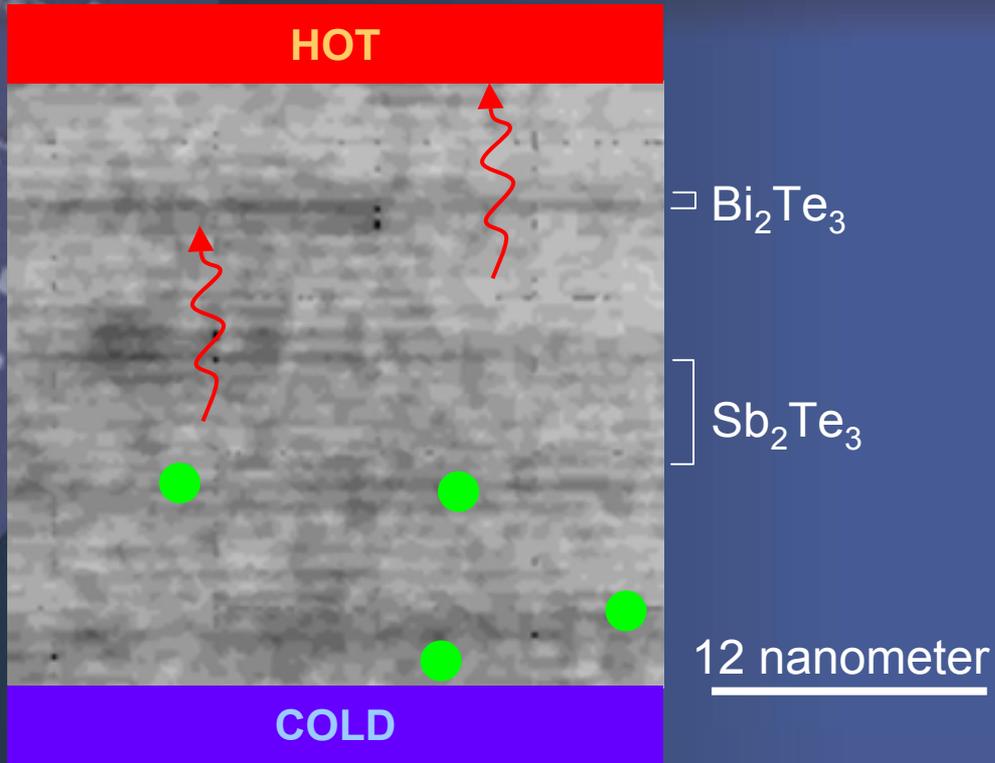
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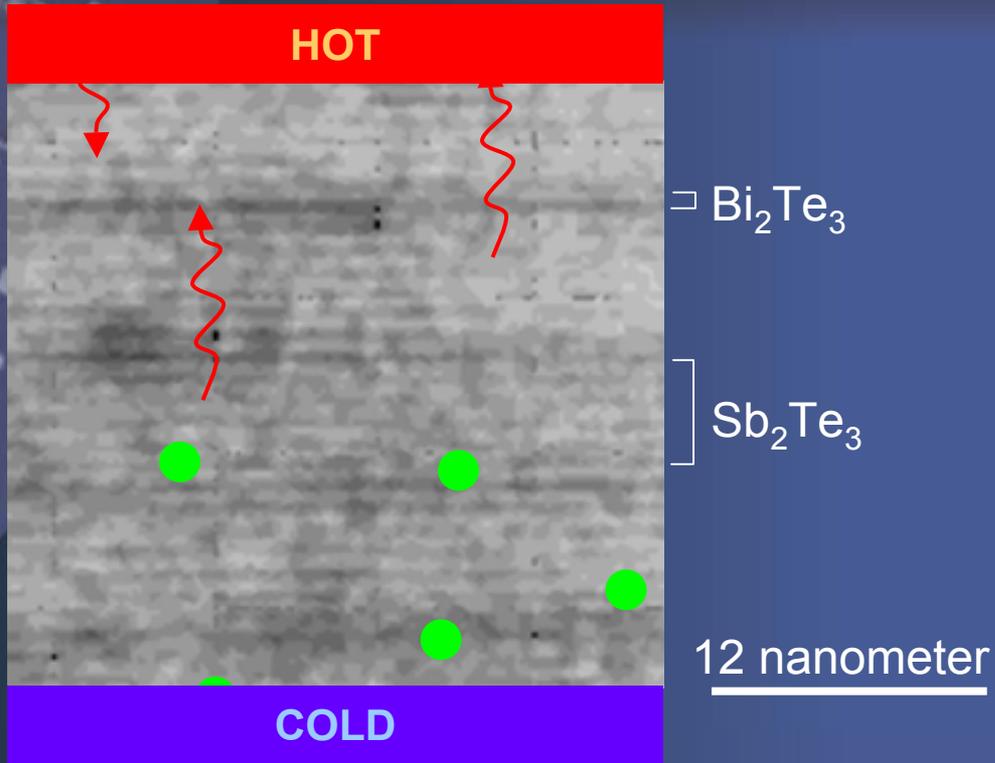
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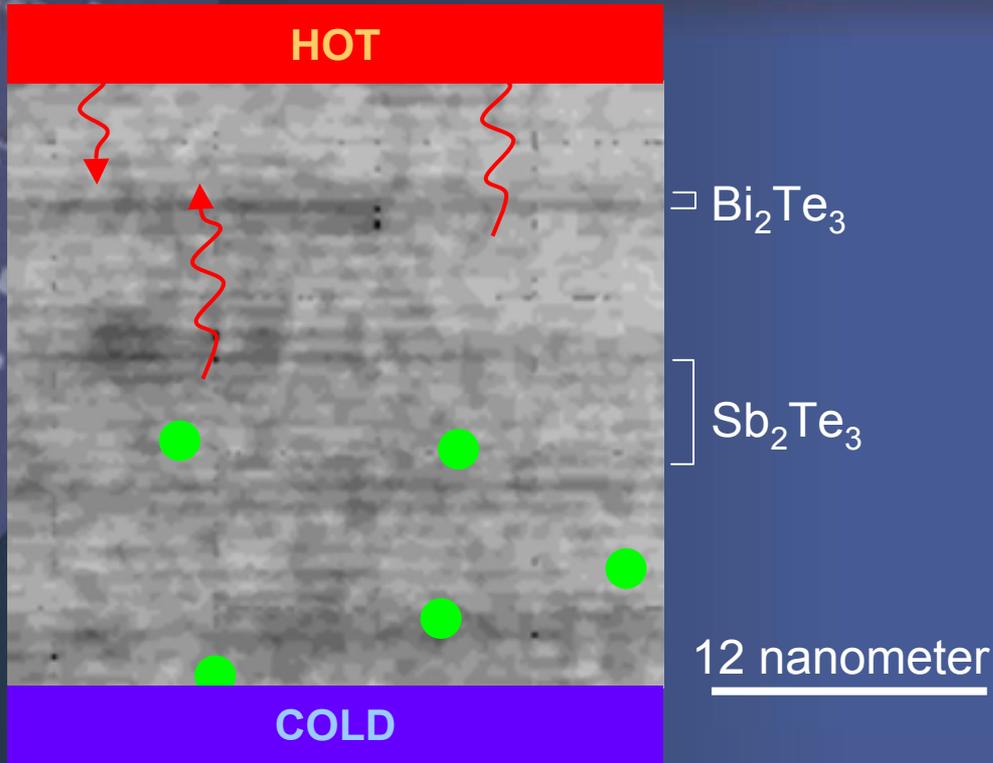
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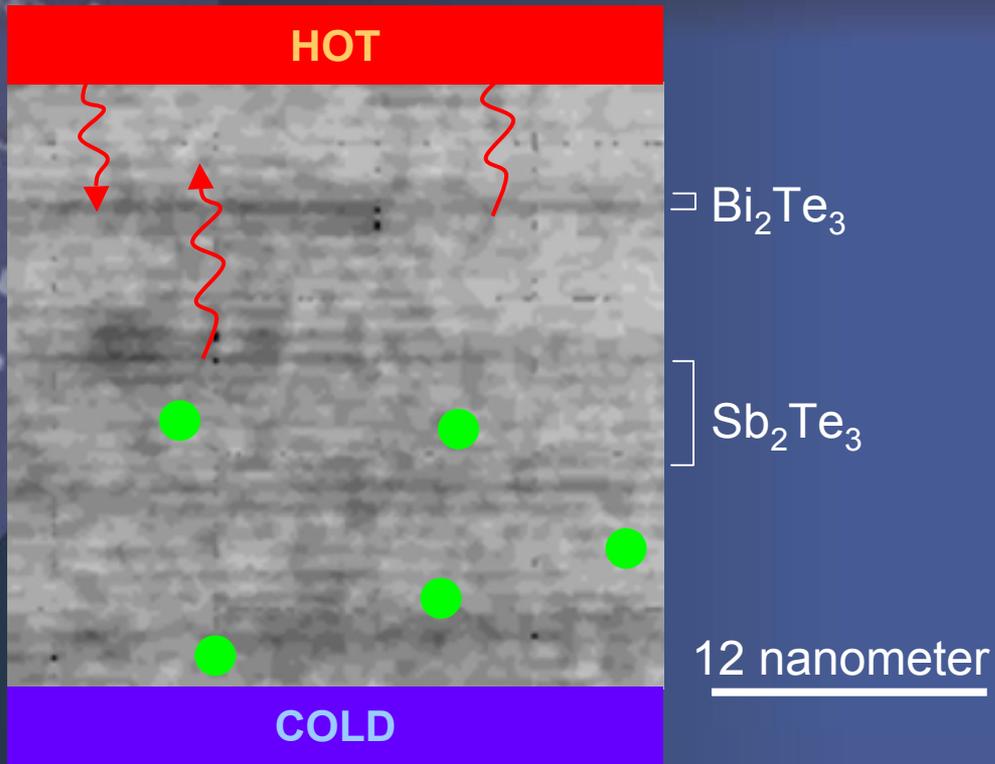
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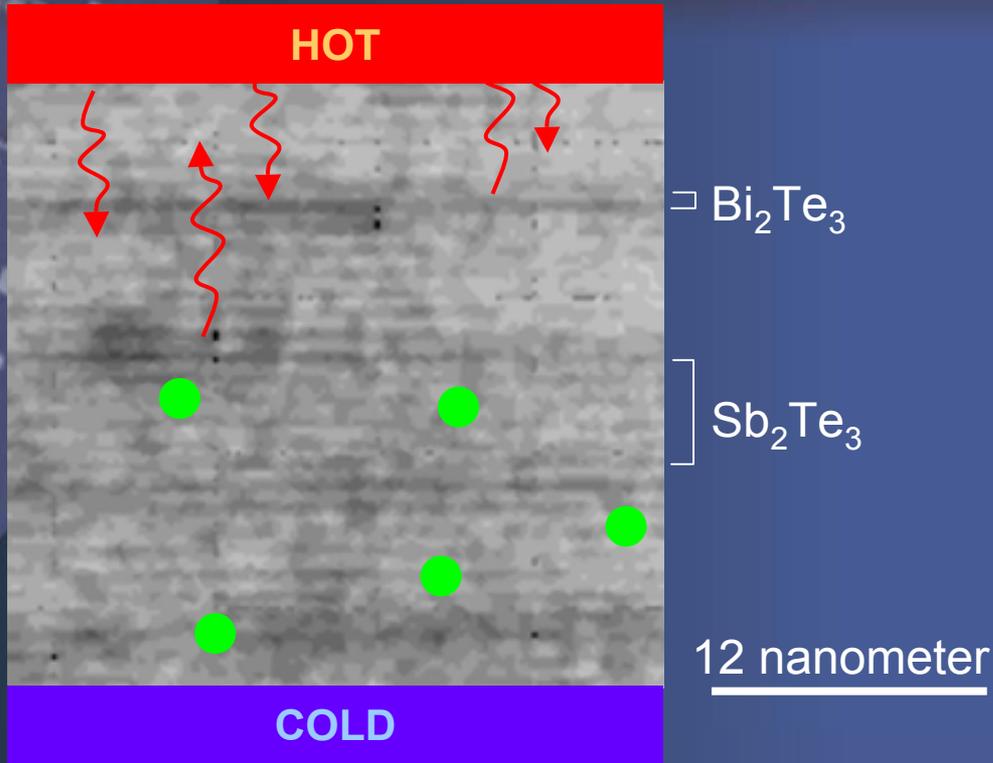
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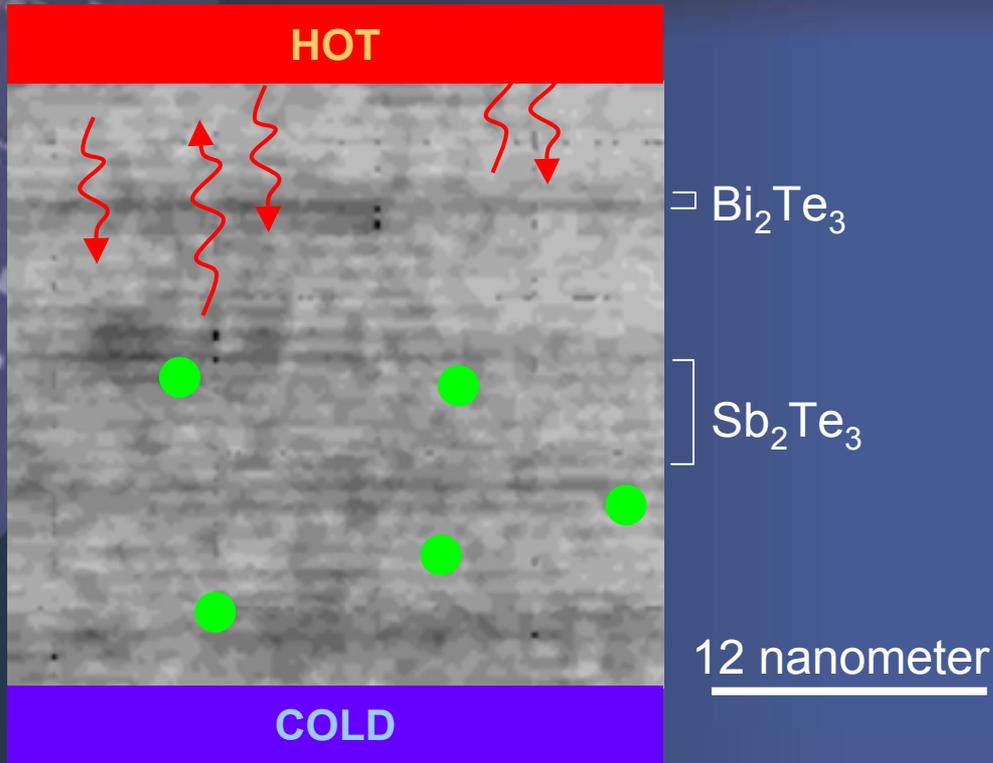
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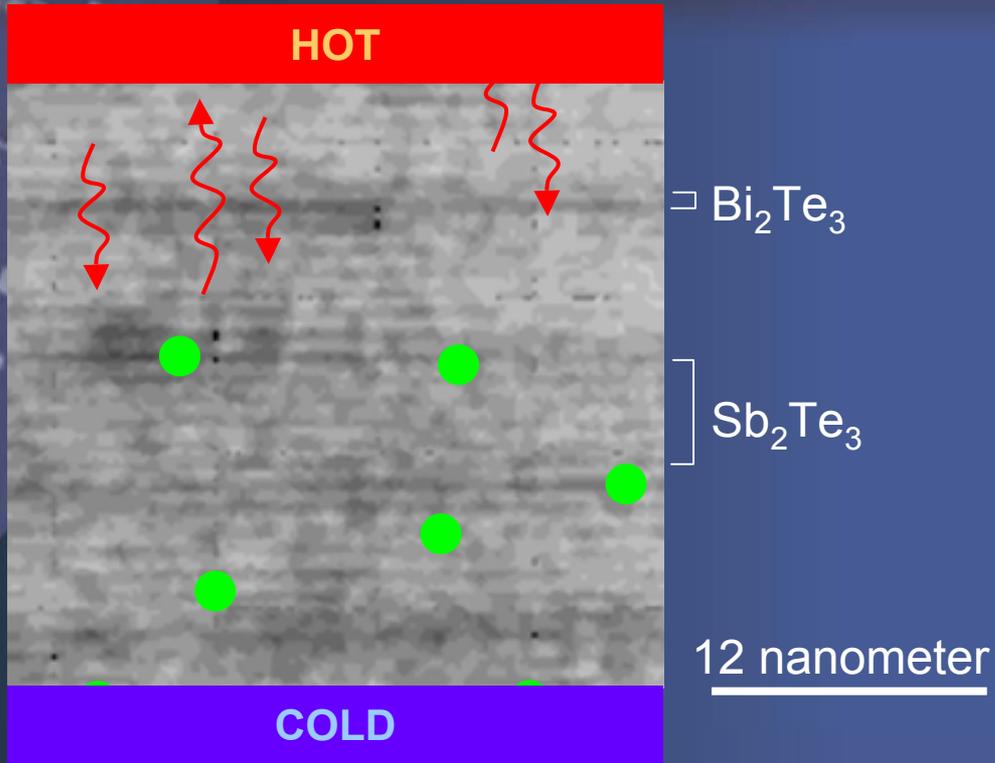
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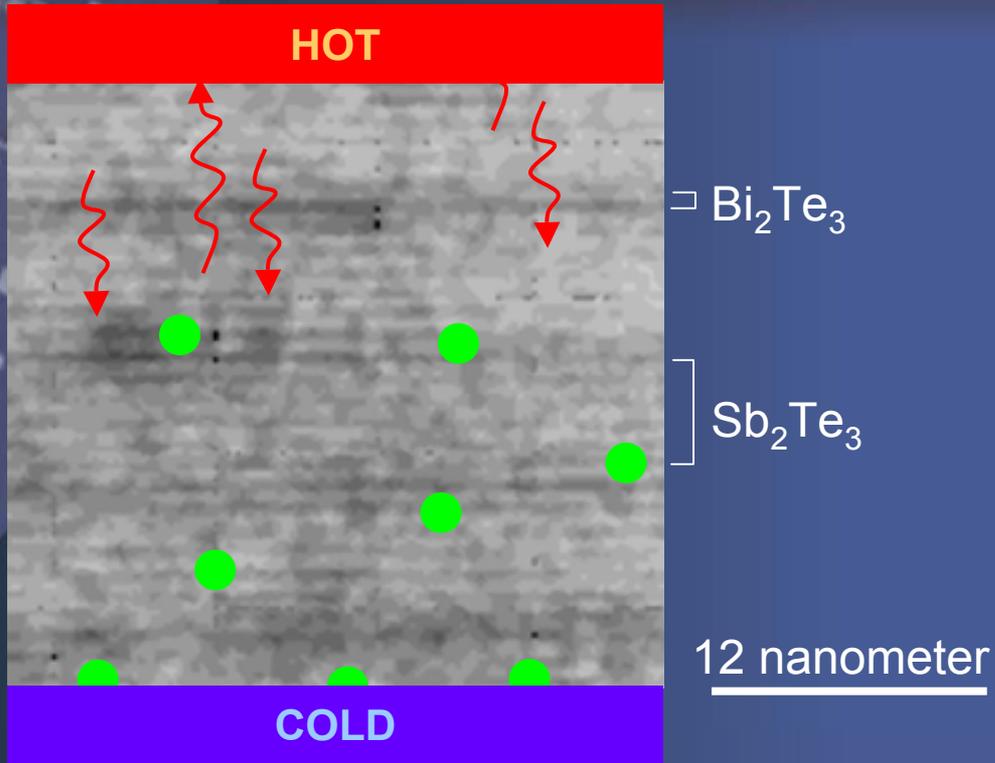
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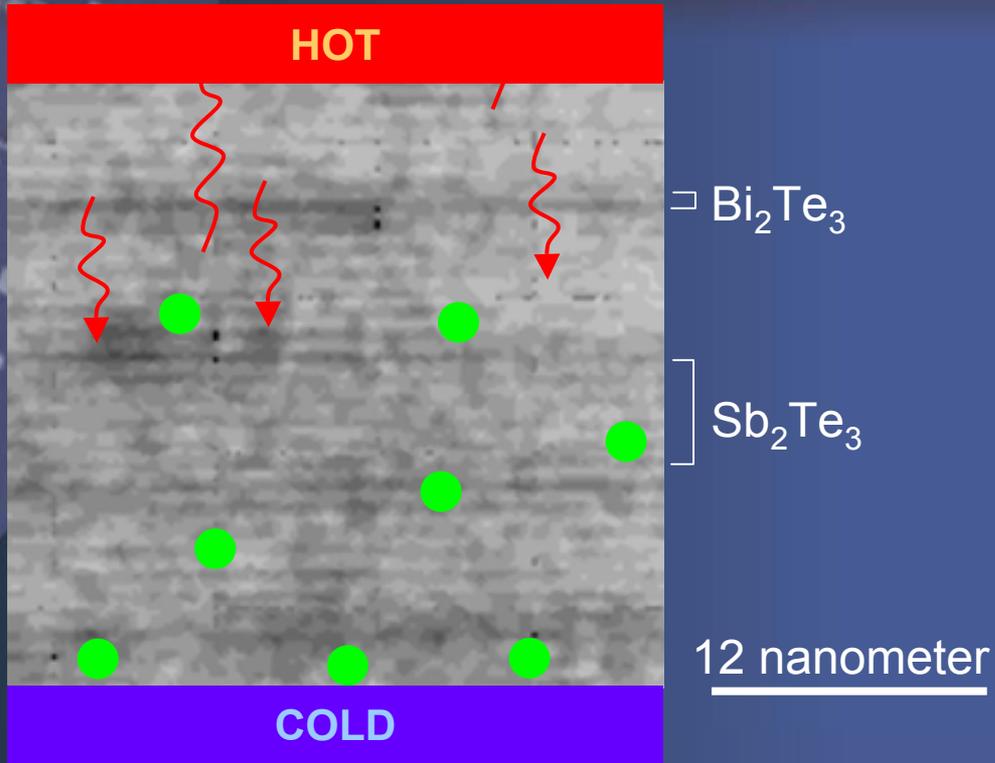
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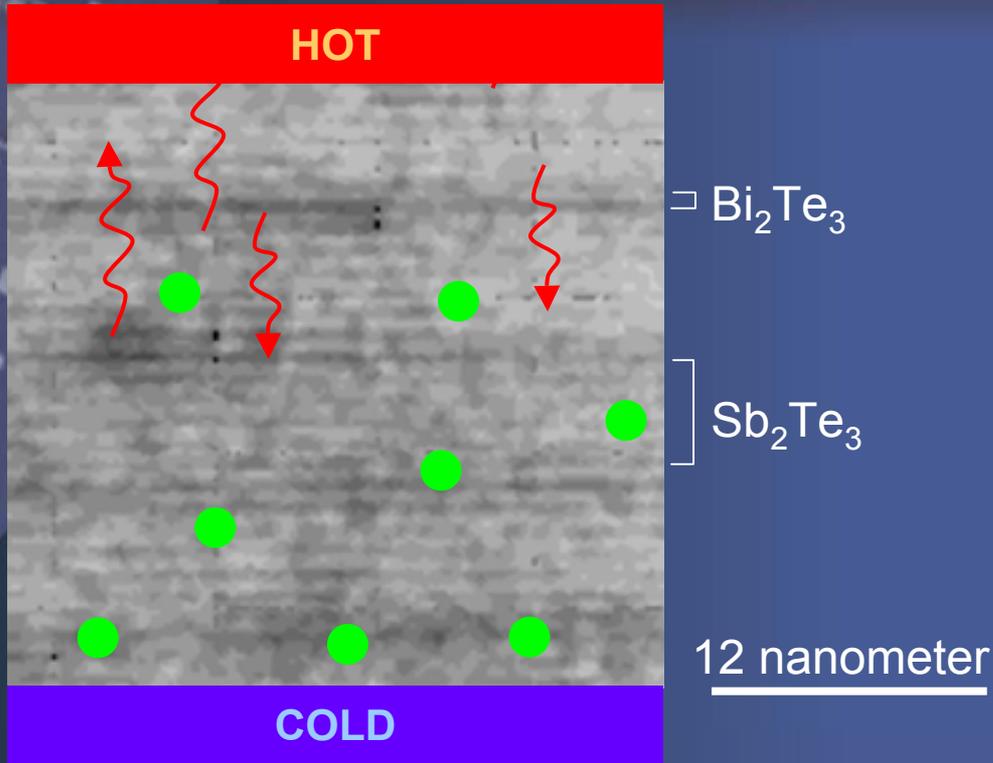
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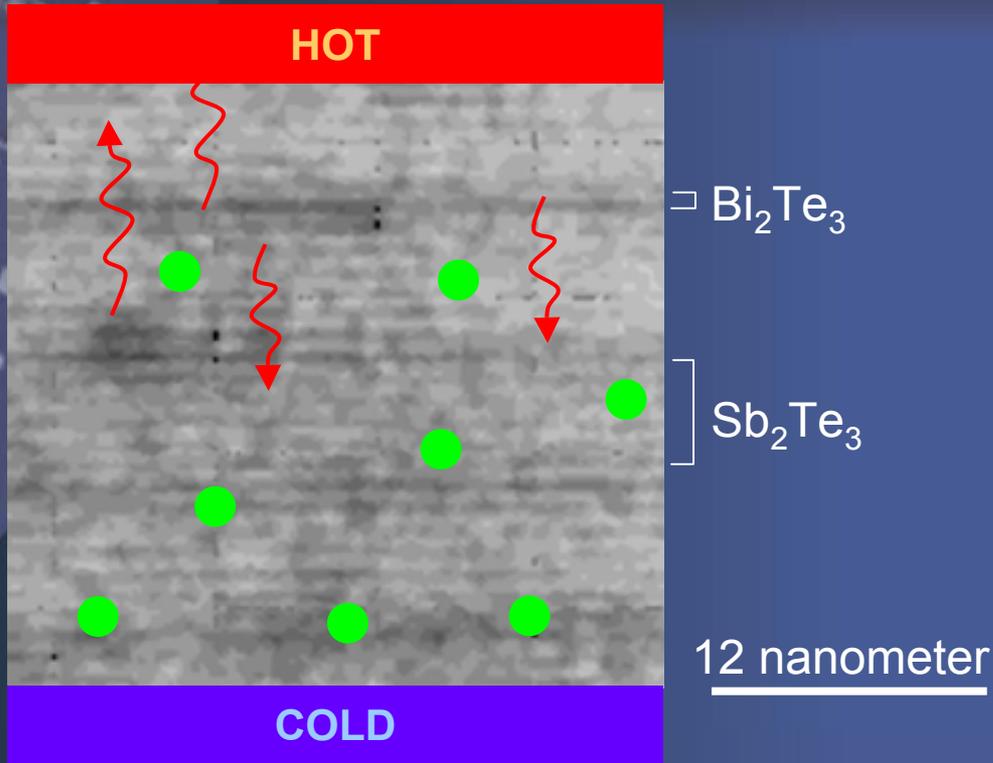
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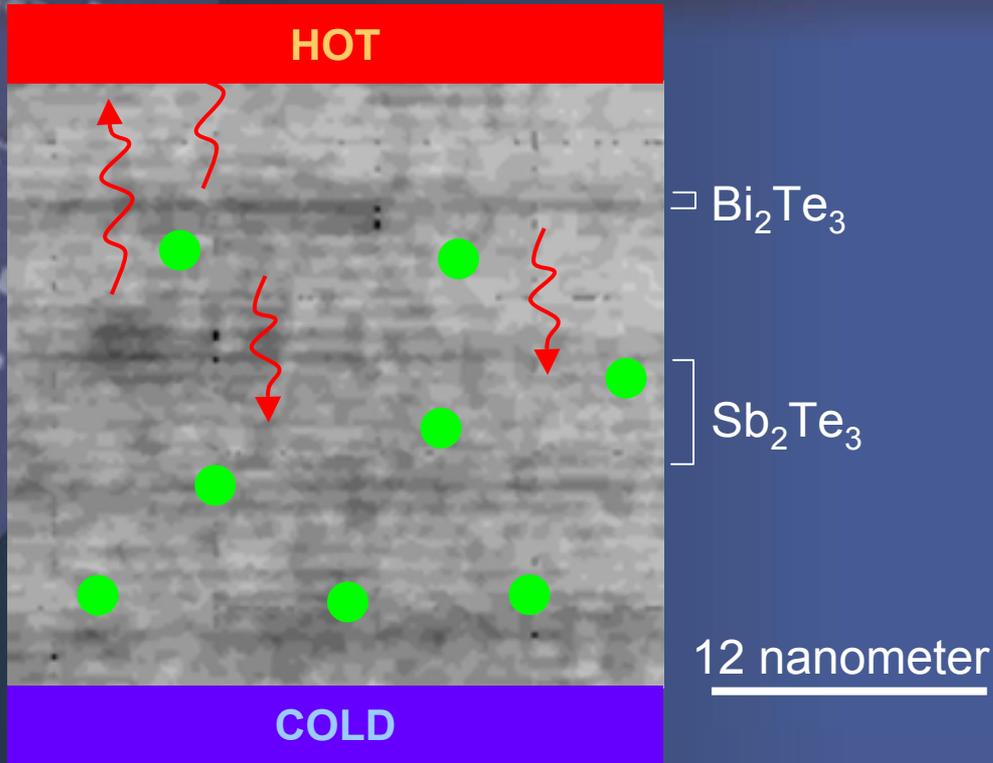
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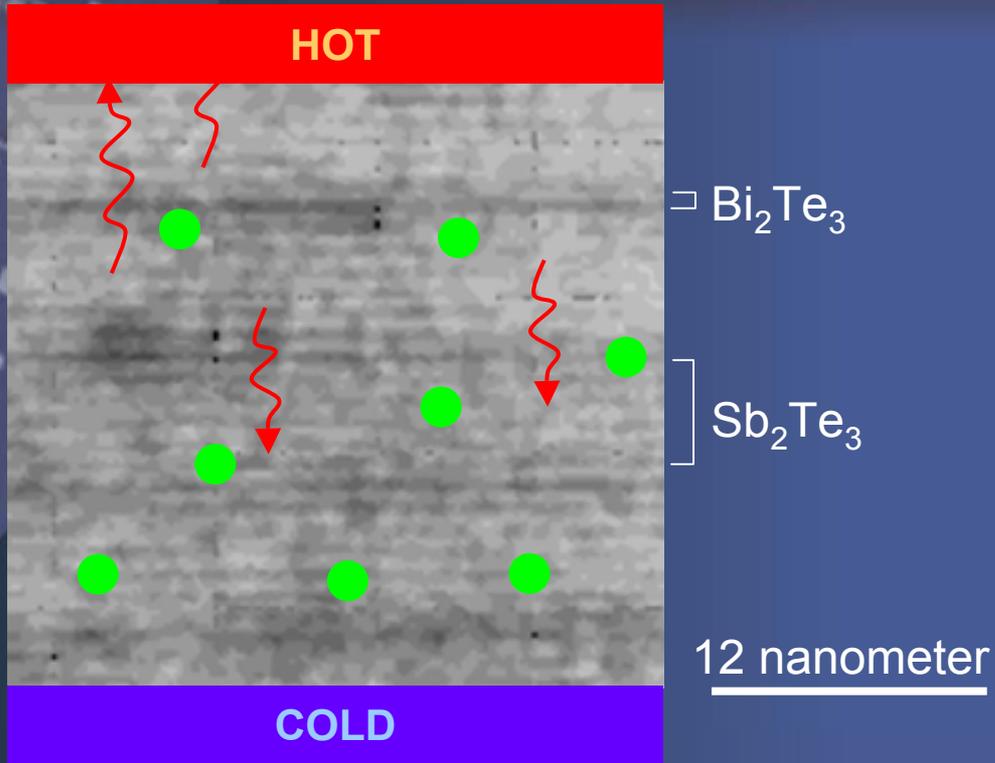
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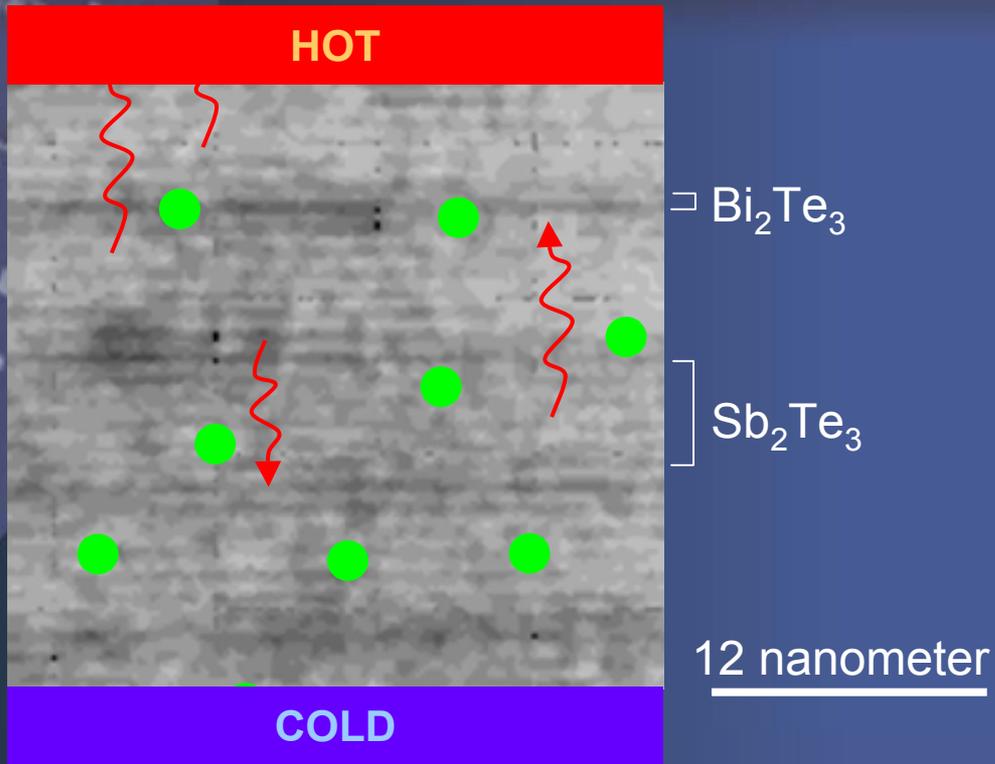
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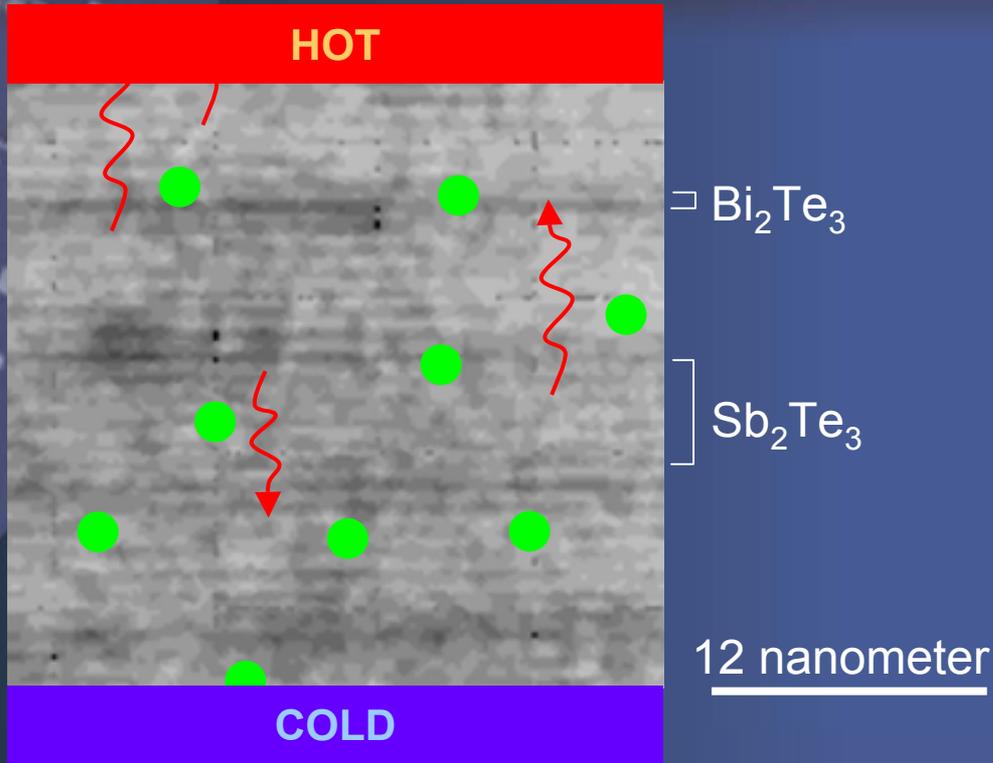
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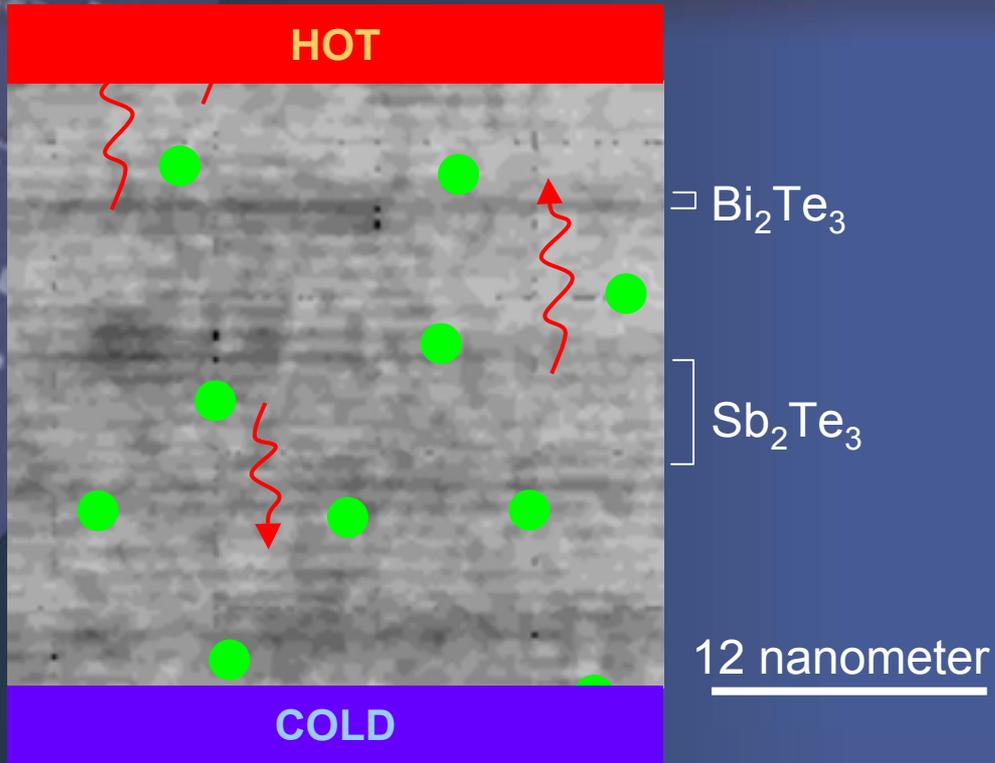
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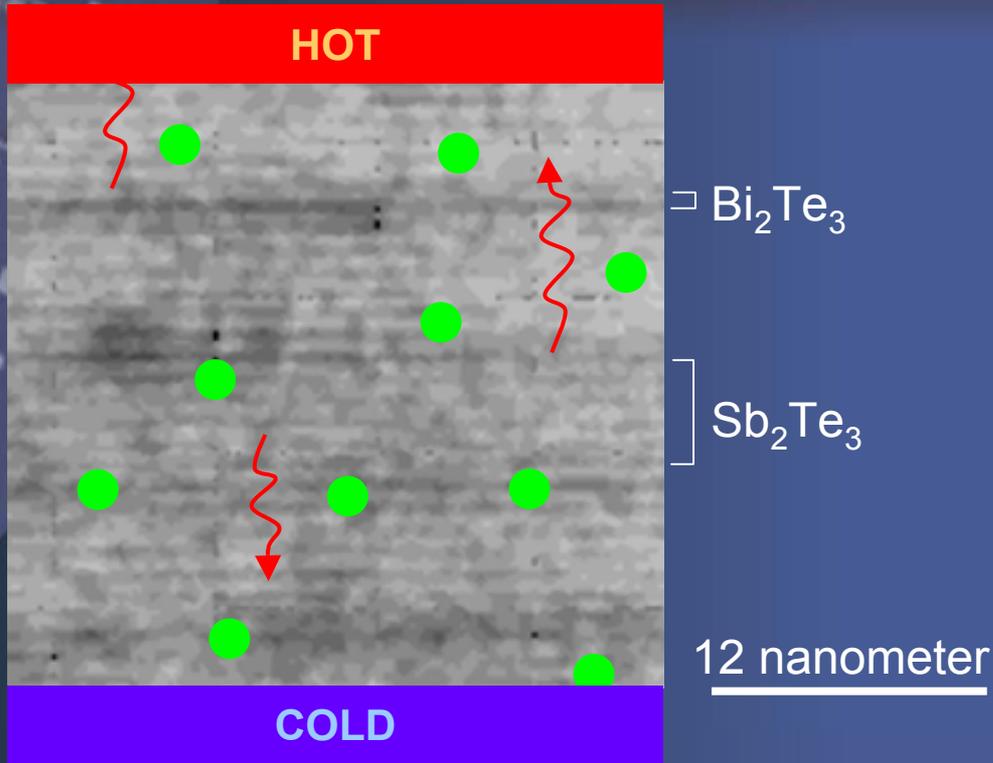
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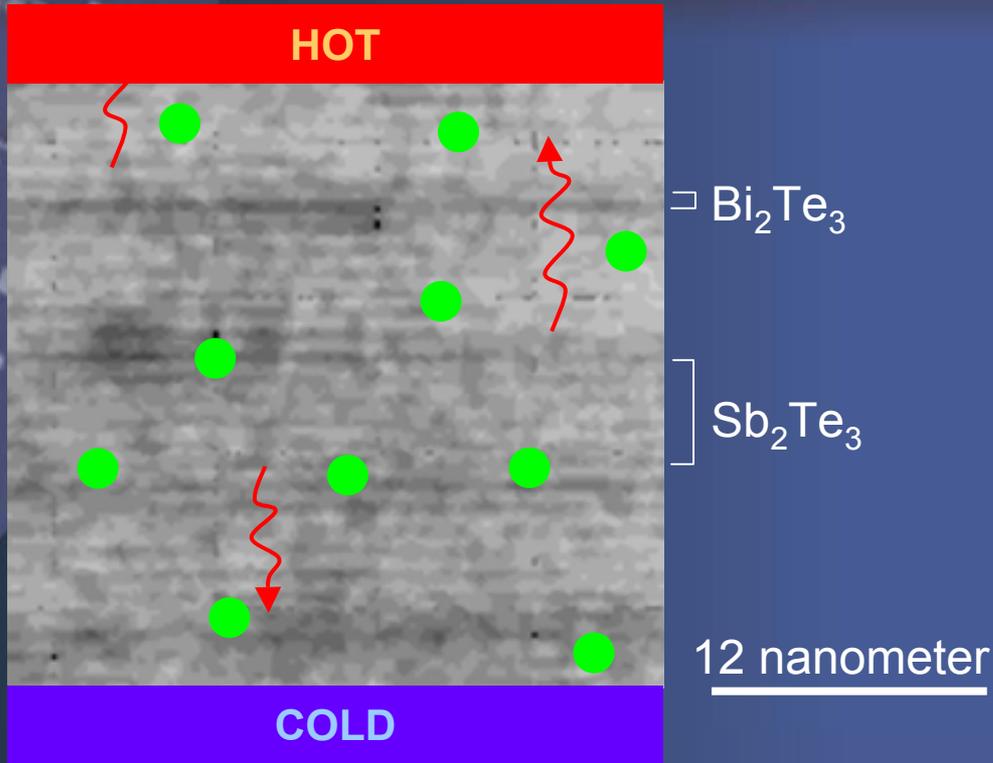
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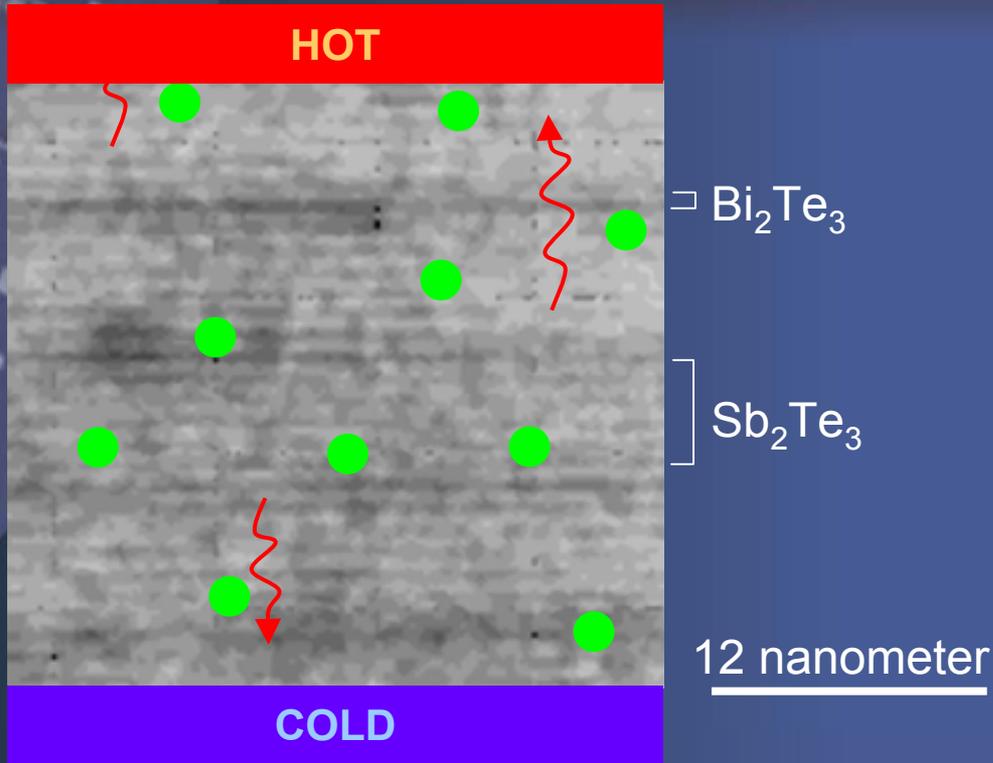
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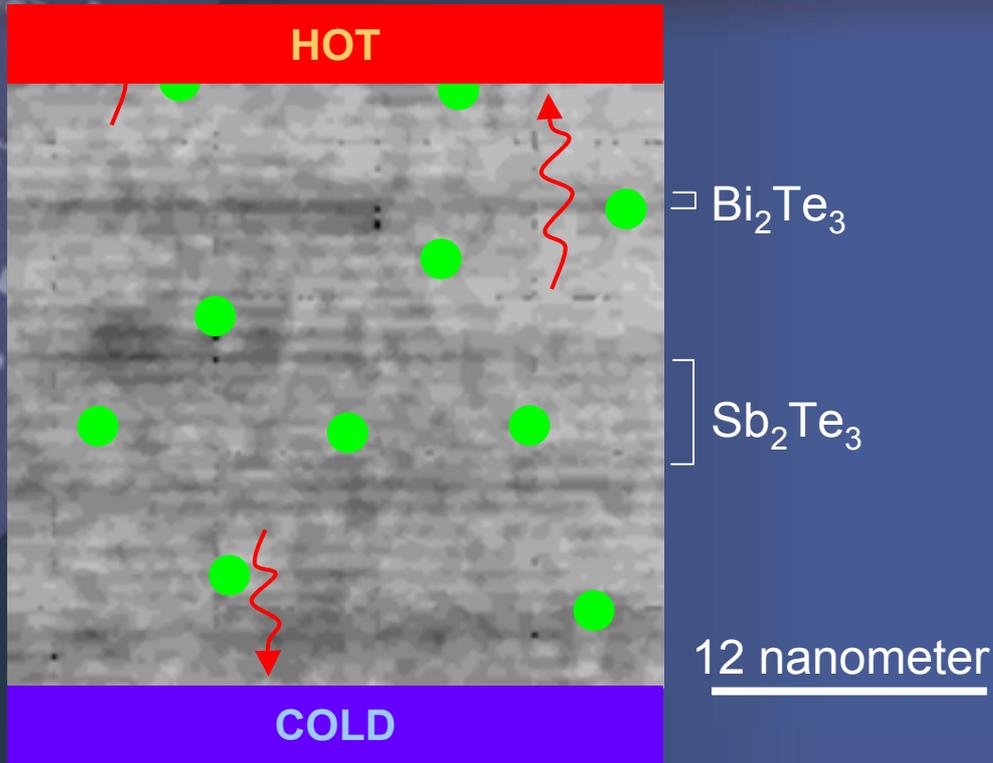
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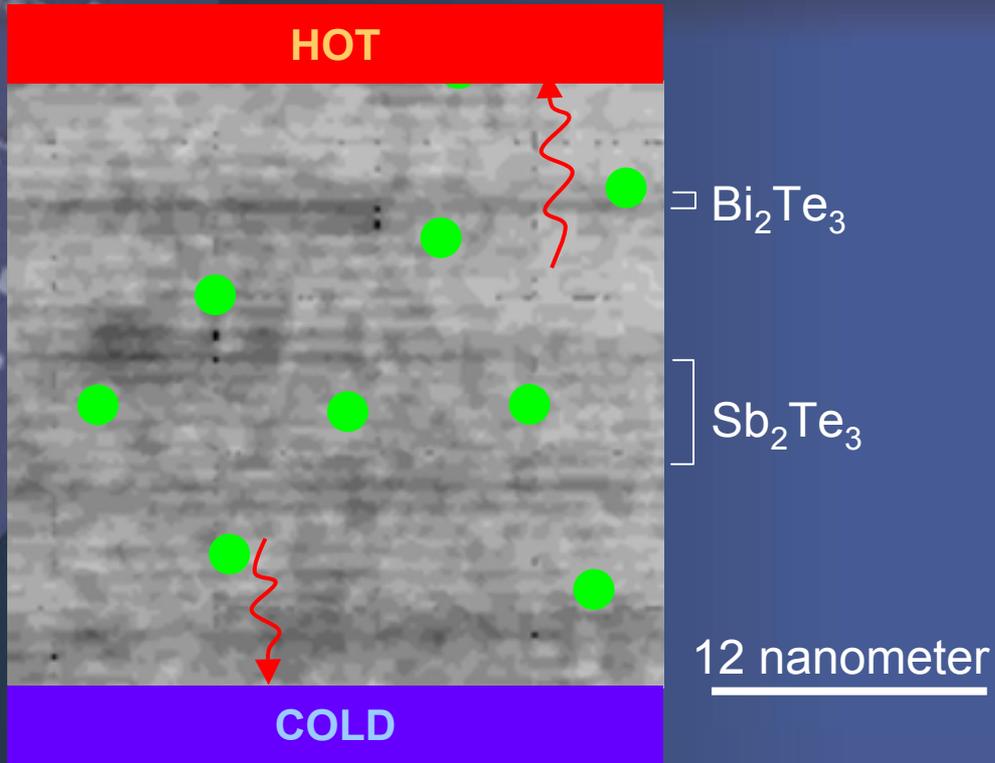
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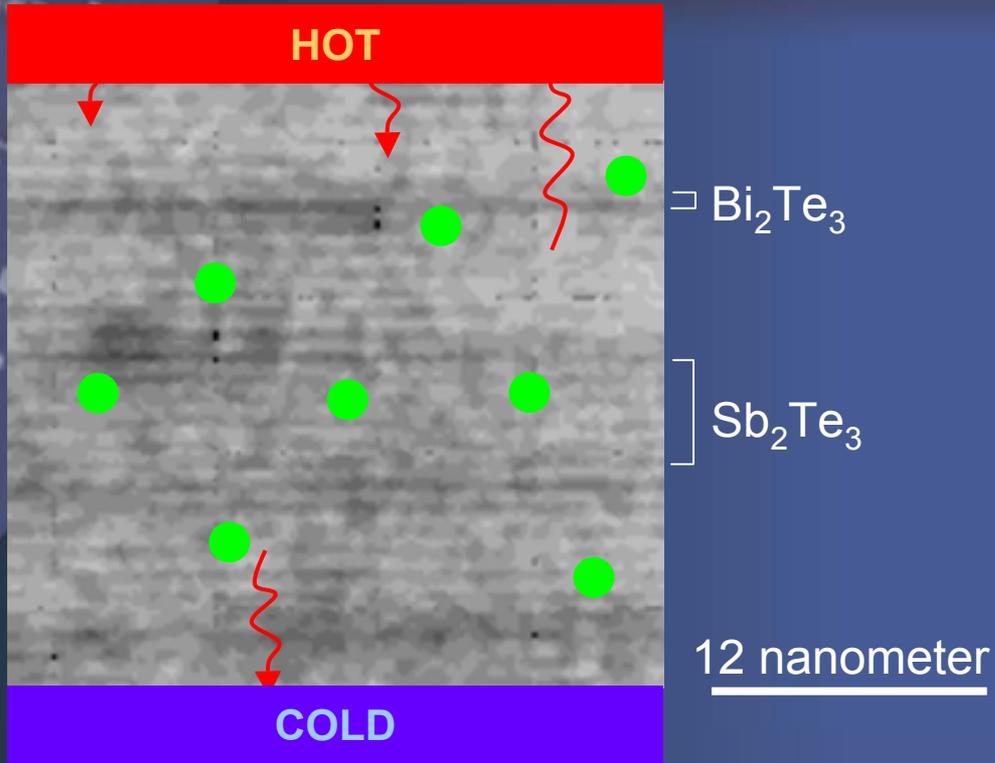
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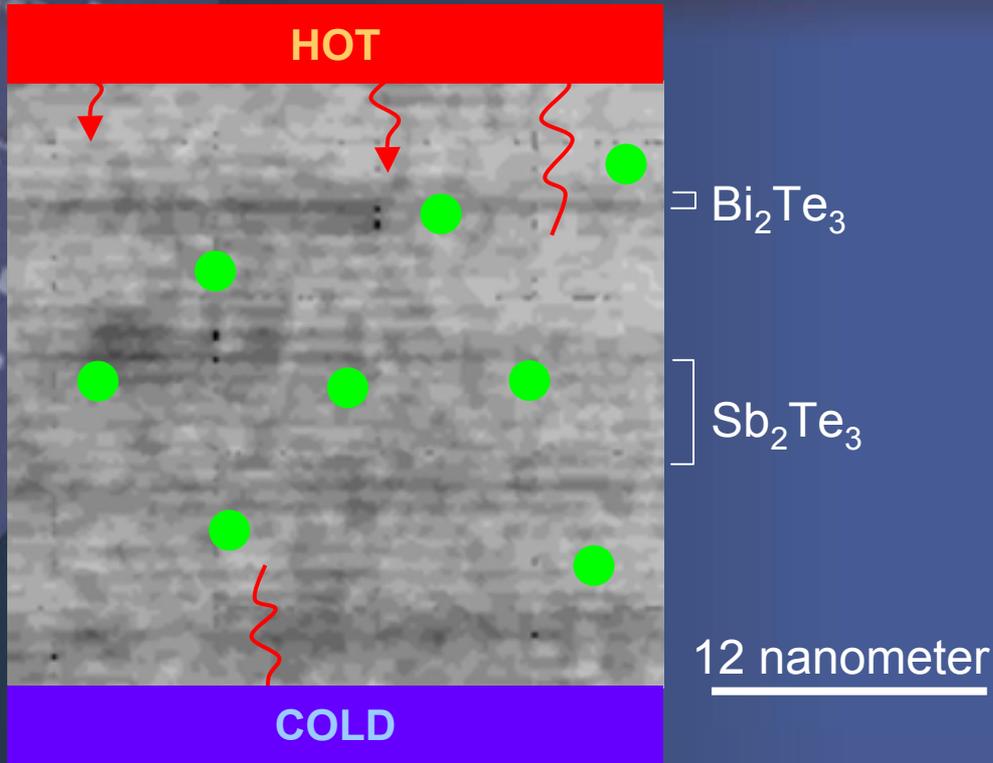
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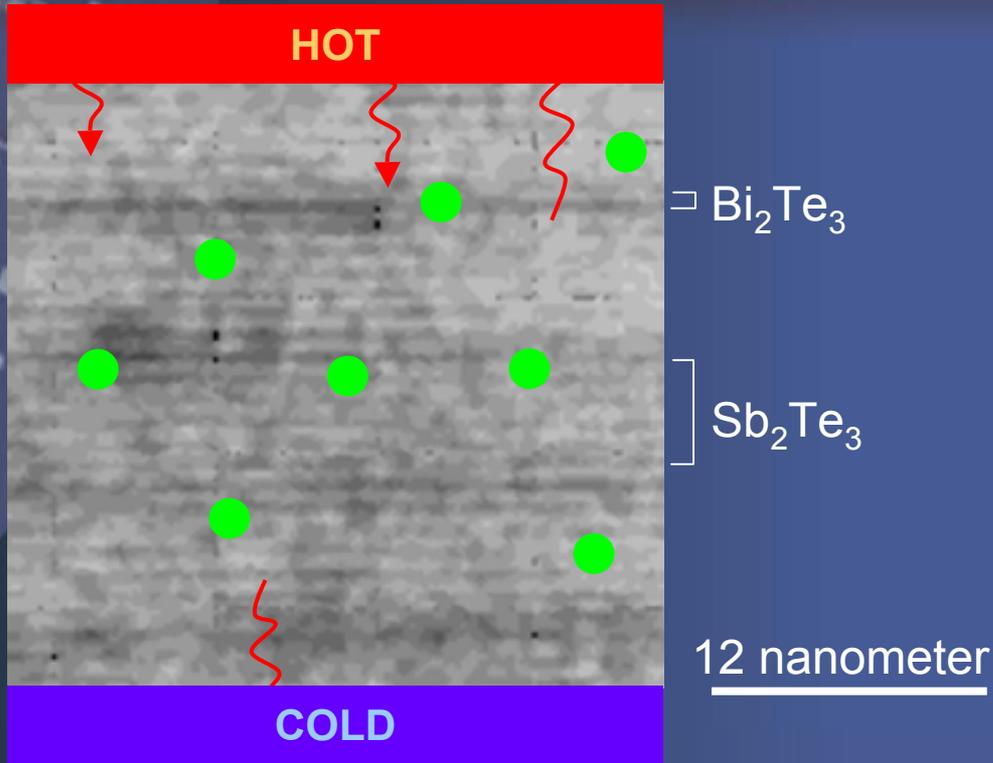
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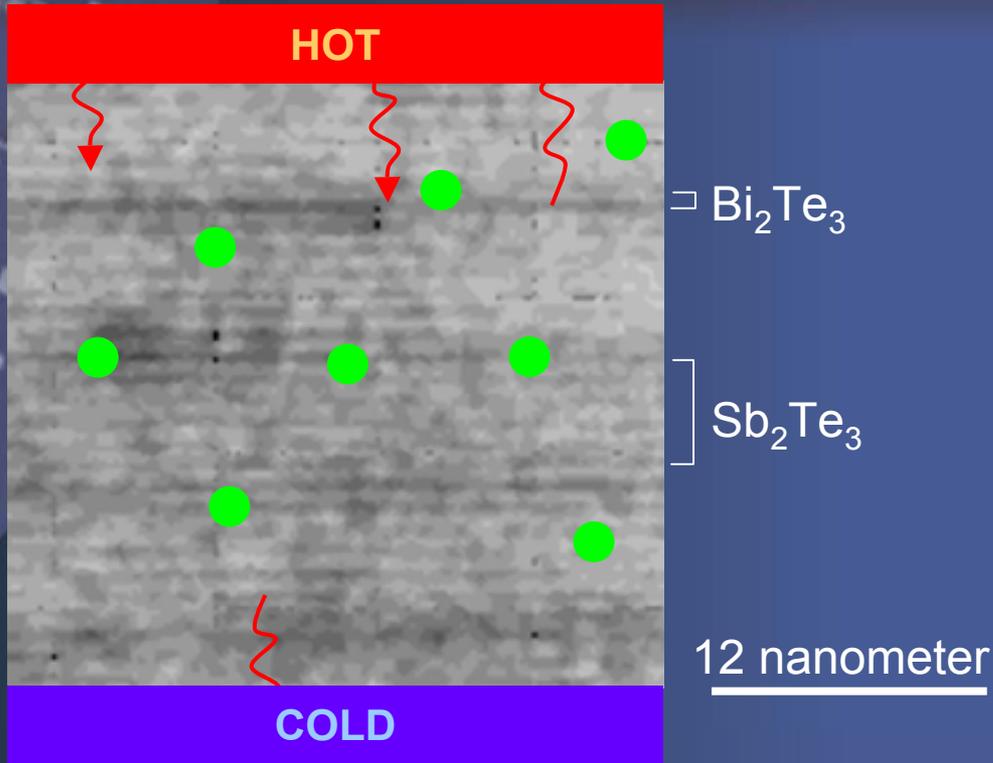
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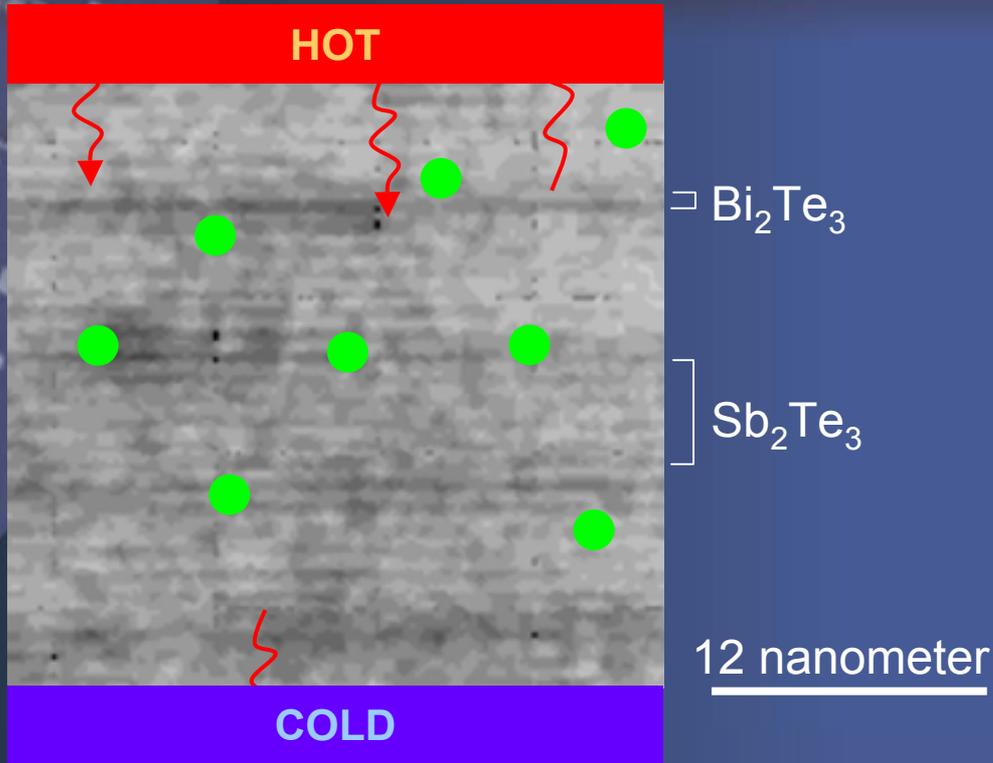
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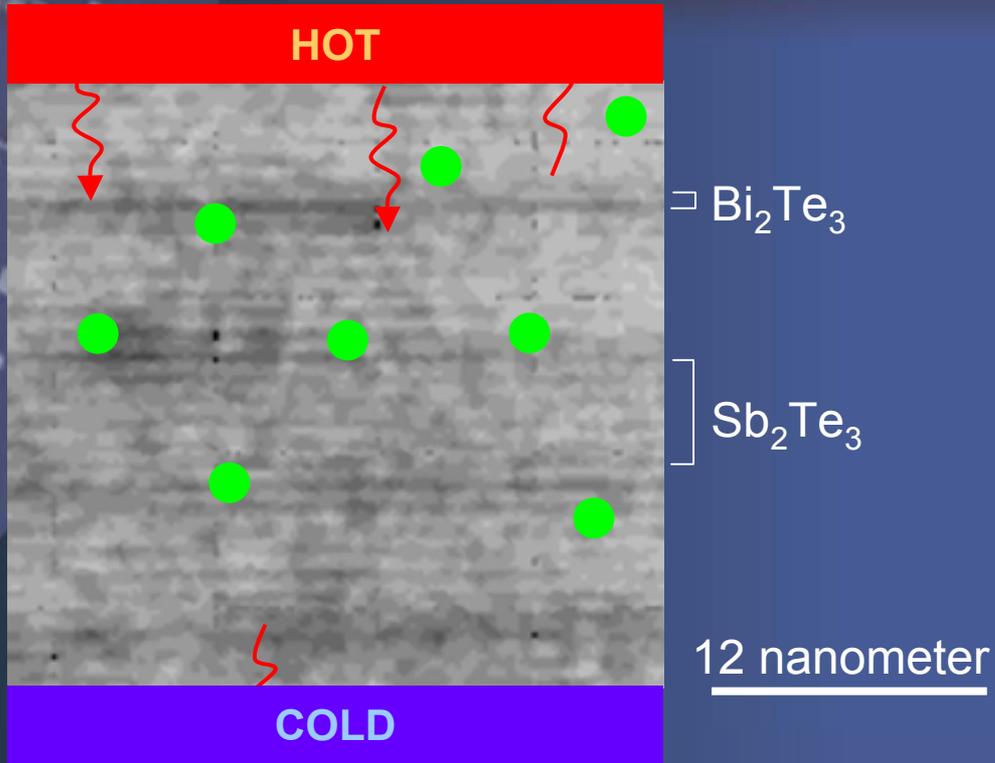
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