Highlights from the 2002
International Conference on Thermoelectrics
Long Beach, California, USA Aug. 26-29, 2002

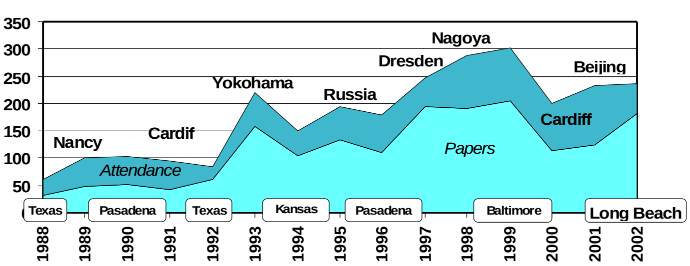
Cronin B. Vining
ZT Services
Auburn, Alabama USA
Phone: +1 (334) 887-2404
FAX: +1 (309) 214-5916
vining@zts.com
http://www.zts.com

7th European Workshop on Thermoelectrics
Universidad Pública de Navarra
Pamplona, Spain
October 3-4, 2002

ICT2002

- 236 attendees
- 104 oral papers
- 77 posters

- ICT2003, Aug. 17-24, 2004 Montpellier, France
- ICT2004, dates TBD Adelaide, Australia!



Selected Highlights

- Power
  - NASA's NSI: **Nuclear Systems Initiative**
    - First serious US space nuclear power in nearly a decade
    - ***Burdick*** (JPL)
  - **Vehicles**
    - **Hendricks** (NREL)
- Cooling
  - **Applications**
    - **Lofy** (Amerigon)**, Mahajan** (Intel)
  - Superlattices & Quantum **Dots**
    - ***Venkatasubramanian*** (RTI), ***Harman*** (MIT-LL), **Johnson** (Oregon)
  - **Wafer-Scale** Mass Production Progress
    - **Böttner** (Fraunhofer)
  - **Best Paper Awards**
    - ***Best Scientific (Heinrich) Paper Award: Ghoshal*** (Nanocoolers)
    - ***Best Application Paper Award: Bell*** (BSST/Amerigon)

ZT Services - Contributions by original authors from ICT2002

Burdick (JPL)

- Burdick, G. 2002 Nuclear Systems Initiative Overview. In *XXI International Conference on Thermoelectrics*. Long Beach, CA USA: IEEE.

ZT Services - Contributions by original authors from ICT2002

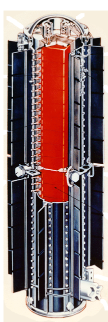
Nuclear Systems Initiative (NSI)

- Safety is the absolute highest priority
- Three components to this technology initiative
  - » Radioisotope power development for potential use on Mars ‘09 and planetary exploration
  - » Nuclear Fission Electric Propulsion research
  - » Nuclear Fission Power research
- This initiative is in addition to the In-Space Propulsion Program already in the OSS budget (FY02)

The Nuclear Systems Initiative will enable a new strategic approach to planetary exploration and is likely to play a key role in NASA’s future

ZT Servic

Nuclear Systems Enabling NASA’s Quest for Life



RPS capabilities enable the search for life’s origins on Mars

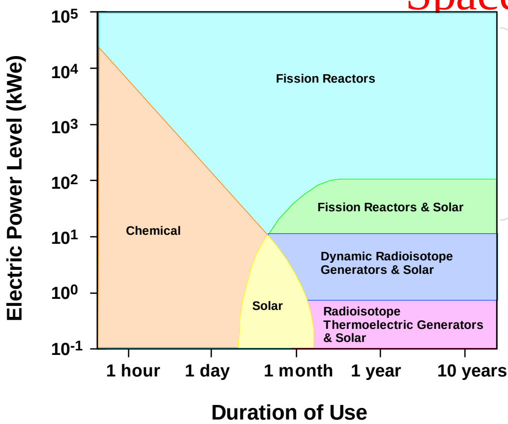
- *Enhance surface mobility*
- *Increased operational options: full-time science exploration*
- *More advanced instruments*
- *Longer life: more sites, more options, greater diversity*

Fission power and propulsion enables exploration not otherwise possible

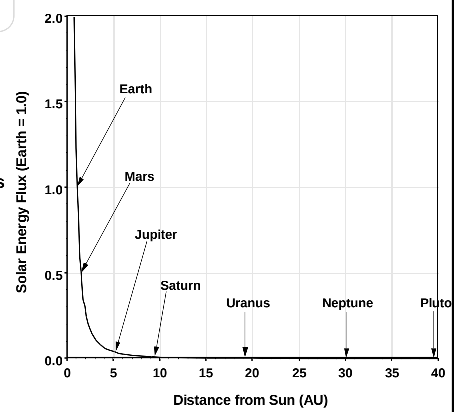
- *Orbiting -- as opposed to fly-by -- missions*
- *Abundant power in deep space: more capable instruments, much greater data rates*
- *Reduced trip time: fast science return*
- *Multiple sites and sample return options*

ZT Services - Contributions by original authors from ICT2002

Why Use Nuclear Systems in Space?



- Long-duration operations (> 1 week)
- High sustained power (> 10-100 kWe)



- Distances where solar power density is too low (> ~1.5 AU)
- Locations where solar power not readily or continuously available (lunar polar craters, high Martian latitudes)

ZT Services - Contributions by original authors from ICT2002

Summary

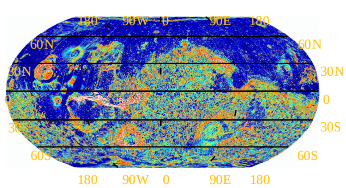
Development of RPS and NEP will revolutionize our ability to study the Solar System's natural laboratories.

Radioisotope power systems enable surface missions

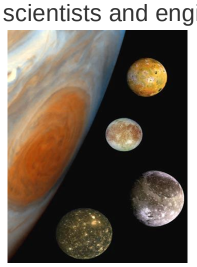
Outer planetary exploration missions are enabled by NEP.

Continue the 30-year relationship with DOE in providing radioisotope systems for space exploration.

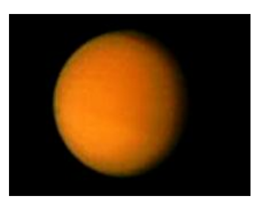
Space exploration, coupled with nuclear systems, has the potential for exciting a new generation of scientists and engineers in the nuclear field.



Mars Surface



Galilean Satellites



Titan

ZT Services - Contributions by original authors from ICT2002

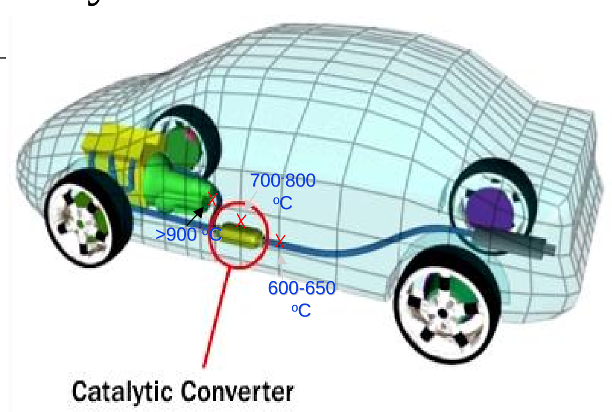
Time for World Class Solutions

Advanced Thermoelectric Power System Investigations for
Light-Duty / Heavy-Duty Vehicle Applications
21st International Conference On Thermoelectrics
Long Beach, CA
28 August 2002

U.S. Department of Energy's National Renewable Energy Laboratory
Terry J. Hendricks, Ph.D., P.E., AHHPS Field Technology Manager
Jason Lustbader

ZT Services - Contributions by original authors from ICT2002

System Placement



ZT Services - Contributions by original authors from ICT2002

How Much Fuel Can Be Saved?

- Potential to Recover 8-10%
  - Light Duty
    - » 45 Billion Gallons Out the Exhaust
    - » Save 30 Billion Gallons/Year
  - Heavy Duty
    - » Save 1.3 Billion Gallons/Year
    - » 5 kW TE System

ZT Services - Contributions by original authors from ICT2002

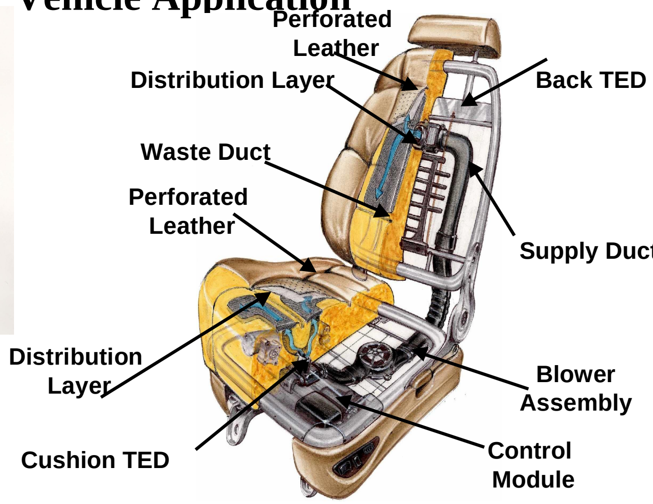
Lofy (Amerigon)

Lofy, J., Bell, L.E. 2002 Thermoelectrics for environmental control in automobiles. In *XXI International Conference on Thermoelectrics*. Long Beach, CA USA: IEEE.

ZT Services - Contributions by original authors from ICT2002

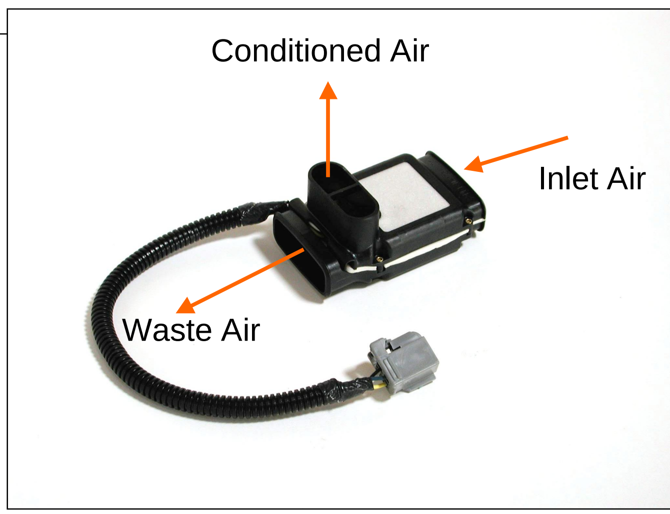
Case Study:
Climate Control Seat™ (CCS™) System Vehicle Application

Production CCS Assembly



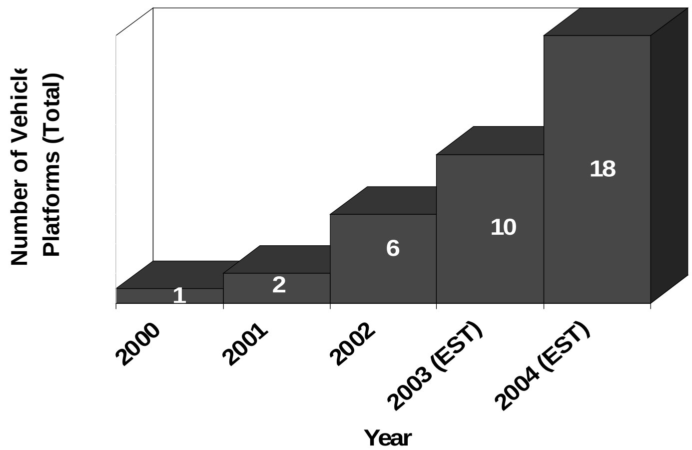
ZT Services - Contributions by original authors from ICT2002

TE Assembly



ZT Services - Contributions by original authors from ICT2002

Growth for CCS Programs



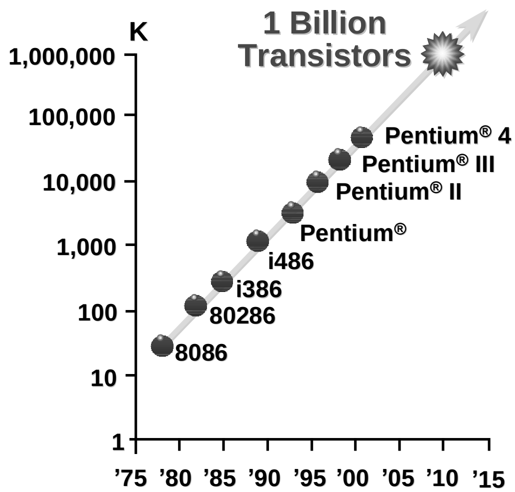
ZT Services - Contributions by original authors from ICT2002

Mahajan (Intel)

Mahajan, R. 2002 Challenges in thermal management of microprocessors. In *XXI International Conference on Thermoelectrics*. Long Beach, CA USA: IEEE.

ZT Services - Contributions by original authors from ICT2002

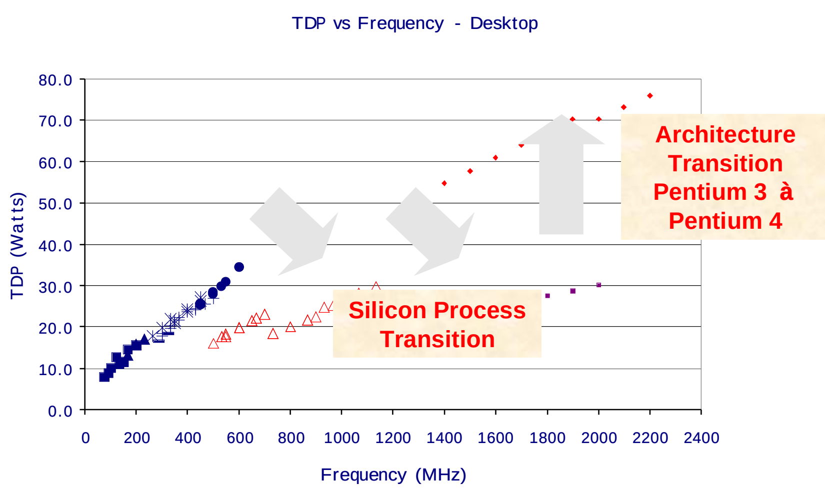
Moore’s Law Drives Industry



Source: Intel

ZT Services - Contributions by original authors from ICT2002

Thermal Design Power

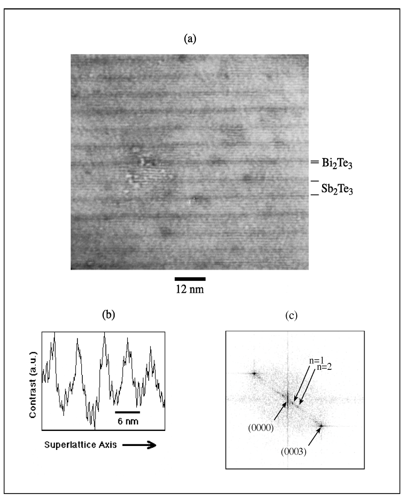


ZT Services - Contributions by original authors from ICT2002

Venkatasubramanian (RTI)

- Venkatasubramanian, R., Siivola, E., Colpitts, T., O'Quinn, B., Coonley, K., Addepali, P., Posthill, J. & Puchan, M. 2002 Thin-film superlattice thermoelectric devices for power generation and cooling. In *XXI International Conference on Thermoelectrics*. Long Beach, CA USA: IEEE.

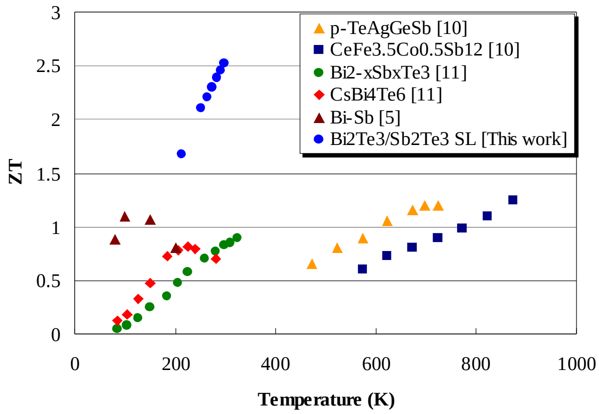
RTI's Nano-structured Superlattice Material



Applied Physics Letters, 75, 1104 (1999)

- 10Å/50Å Bi_2Te_3/Sb_2Te_3 Structure
- Optimized for disrupting heat transport while enhancing electron transport perpendicular to the superlattice interfaces

Temperature dependence of ZT in p -type Bi_2Te_3/Sb_2Te_3 Superlattices (213-300K) – promise for cryogenic applications

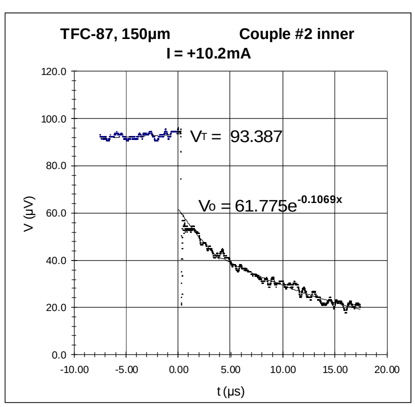


***Nature*, 413, 597 (2001)**

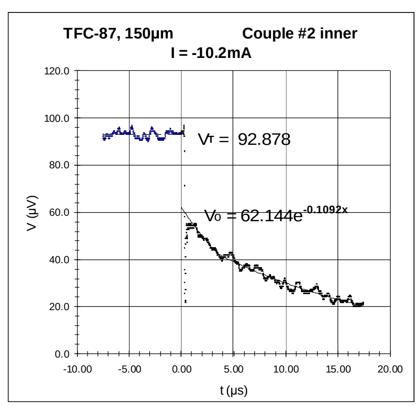
ZT Services - Contributions by original authors from ICT2002

Transient Method ZT on Modified Processing of p-n couple to overcome the interconnect resistance issue

ZT ~1.95



ZT ~2.02

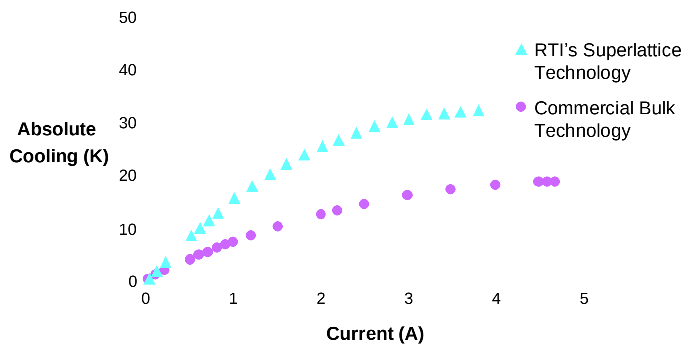


- **Measurements on similar bulk p-n couple shows ZT ~ 0.77**
  - Thus now have translated the individual ZT of p- and n- SL materials to the ZT of couple - the fundamental cooling or power unit

ZT Services - Contributions by original authors from ICT2002

Advantages of RTI's Superlattice Thermoelectric Technology

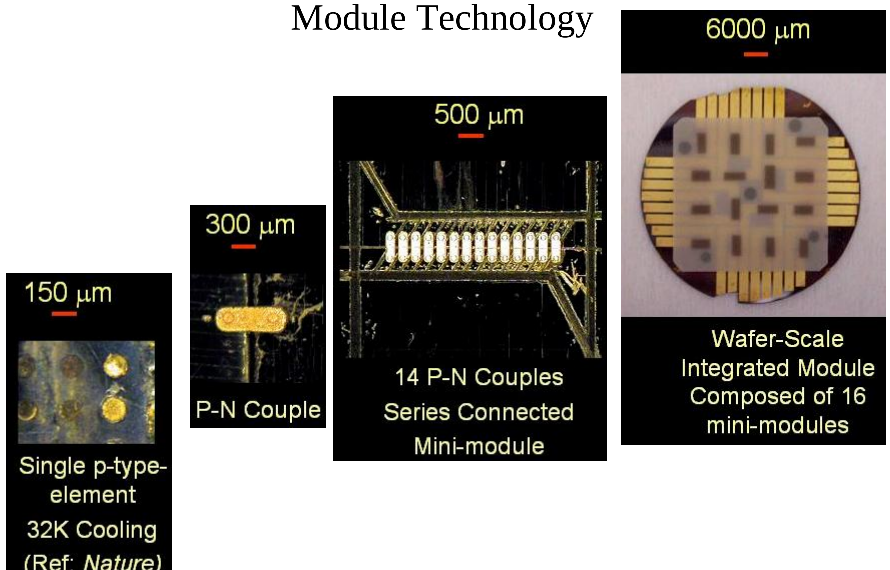
- Enhanced cooling



- Other "truly" thin-film (thickness of films less than 10 microns) technologies have one-tenth the cooling of the RTI superlattice device elements at 300K

z

Progress in RTI's Superlattice Thermoelectric Module Technology



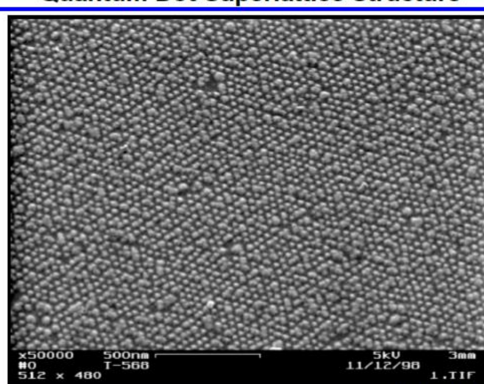
ZT Services – Contributions by original authors from ICT2002

Harman (MIT-LL)

Harman, T. C. 2002 FE-SEM Image of $PbSe_{0.98}Te_{0.02}/PbTe$ Quantum Dot Superlattice Structure. In *XXI International Conference on Thermoelectrics*. Long Beach, CA USA: IEEE.

ZT Services - Contributions by original authors from ICT2002

FE-SEM Image of $PbSe_{0.98}Te_{0.02}/PbTe$
Quantum Dot Superlattice Structure



MIT Lincoln Laboratory

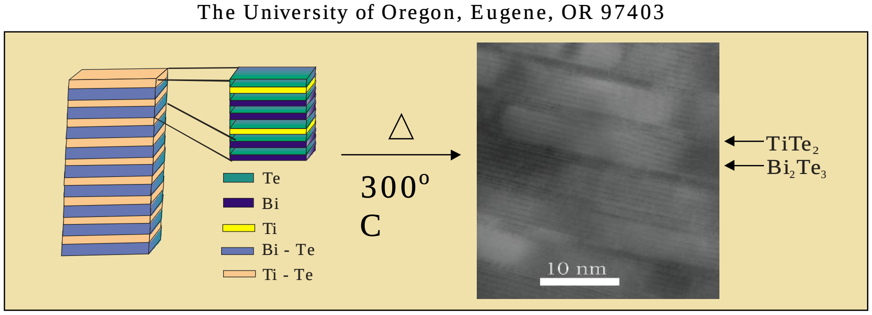
ZT Services - Contributions by original authors from ICT2002

Johnson & Harris (U. Oregon)

- Johnson, D. C. 2002 The synthesis of metastable skutterudites and crystalline superlattices. In *XXI International Conference on Thermoelectrics*. Long Beach, CA USA: IEEE.

Nanoscale Tailoring of Materials using Modulated Elemental Reactants

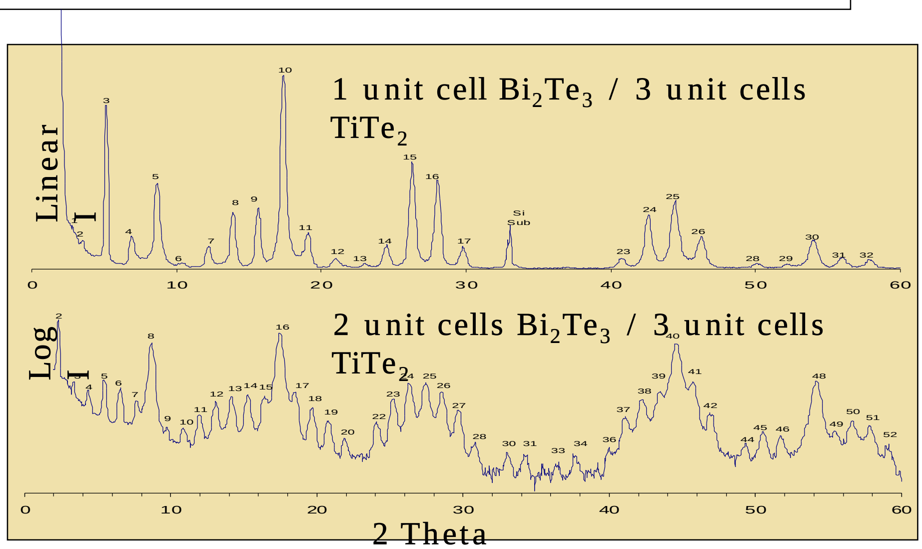
Fred R. Harris and David C. Johnson, Materials Science Institute,
The University of Oregon, Eugene, OR 97403



- Can prepare new compounds not found on phase diagrams
  - (Example: Sb from effusion cell @ 0.5 Å/sec. - CBV)
- Can prepare superstructures by design of initial reactants
- Permits study of interdiffusion and compound formation at reacting interfaces

UNIVERSITY OF OREGON

XRD patterns of Bi_2Te_3 / $TiTe_2$ Superlattices Showing Unit Cell Control



ZT Services - Contributions by original authors from ICT2002

Böttner (Fraunhofer)

Böttner, H. 2002 Thermoelectric micro devices: current state, recent developments and future aspects for technological progress and applications. In *XXI International Conference on Thermoelectrics*. Long Beach, CA USA: IEEE.

Also

Nurnus, J., Böttner, H., Kunzel, C., Vetter, U., Lambrecht, A., Schumann, J. & Volklein, F. 2002 Thin film based thermoelectric energy conversion systems. In *XXI International Conference on Thermoelectrics*. Long Beach, CA USA: IEEE.

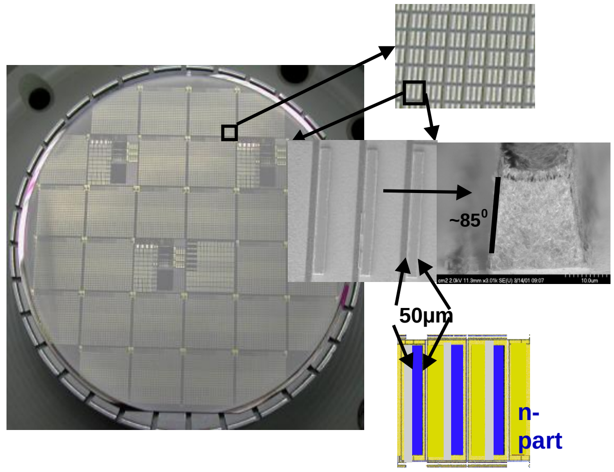
ZT Services - Contributions by original authors from ICT2002

“ µm“ materials and MEMS related technologies

~20µm of n- Bi_2Te_3 sputtered upon electrodes

inclusive gleamy solder on the TE material

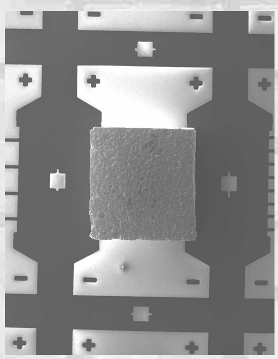
after reactive ion etching

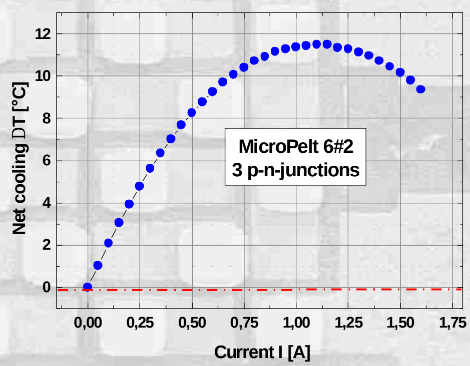


ZT Services - Contributions by original authors from ICT2002

“ µm“ materials and MEMS related technologies

Net cooling 11.6°C @ 1.1 A



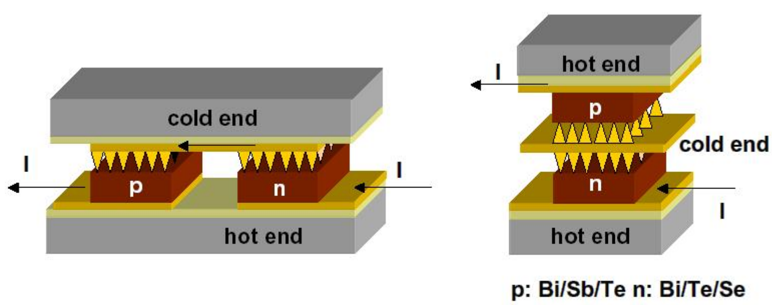


ZT Services - Contributions by original authors from ICT2002

Ghoshal (Nanocoolers/IBM)

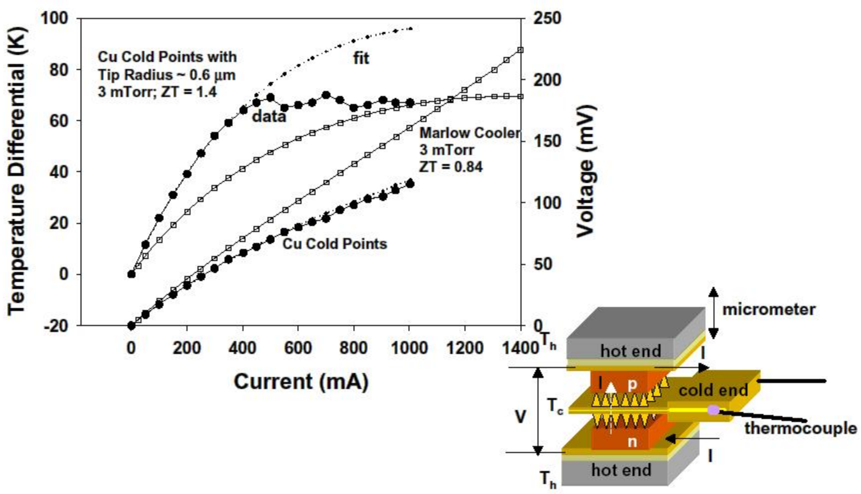
- Ghoshal, U. & Shi, L. 2002 Design and characterization of cold point thermoelectric coolers. In *XXI International Conference on Thermoelectrics*. Long Beach, CA USA: IEEE.

Cold Point Thermoelectric Coolers



Interface Effects: Ju and Ghoshal, *J. Appl. Phys.* (2000)

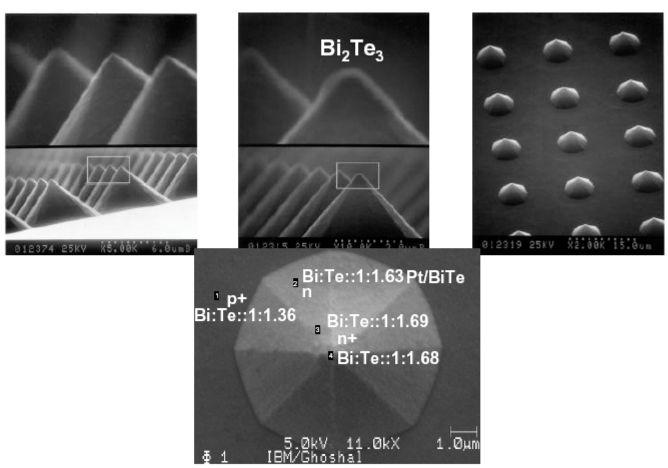
ZT Services - Contributions by original authors from ICT2002



Ghoshal *et al.*, *Appl. Phys. Lett.* (2002)

9

TE Cold Points on Metal/Si



Bell/Amerigon

- Bell, L. E. 2002 Use of thermal isolation to improve thermoelectric system operating efficiency. In *XXI International Conference on Thermoelectrics*. Long Beach, CA USA: IEEE.
- Also
- Diller, R. W. & Chang, Y.-W. 2002 Experimental results confirming improved performance of systems using thermal isolation. In *XXI International Conference on Thermoelectrics*. Long Beach, CA USA: IEEE.

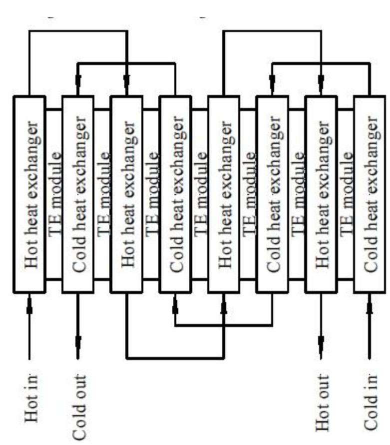
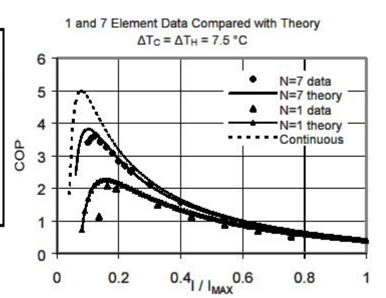


Figure 1. Test specimen schematic, cross-flow connections.



ure 2. 1 and 7 element efficiency improvement at total
perature difference of 15 °C

Supplementary Material

Ghamaty (Hi-Z)

- Ghamaty, S. & Elsner, N. 2002 Thermoelectric QW Device. In *XXI International Conference on Thermoelectrics*. Long Beach, CA USA: IEEE.

News Release
Hi-Z Announces High Efficiency Thermoelectric Materials

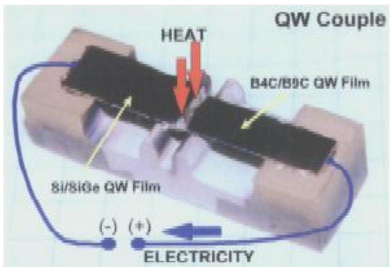


Figure 1. Quantum Well Thermoelectric Couple on 5μm Si

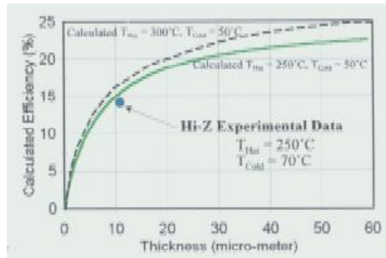


Figure 2. Efficiency of QW couple versus film thickness on a 5μm Si substrate. Hi-Z experimental and predicted values are shown for comparison for N type Si/SiGe and P type B_4C/B_9C.

ZT Services - Contributions by original authors from ICT2002