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14. ABSTRACT

The main objective of the Clemson / DARPA project is to search for and achieve higher performance low temperature (100 K to 250 K) thermoelectric materials than exist to date. Dr. Tritt?s group at Clemson University will perform synthesis and characterization of a number of low dimensional systems which show potential for use in thermoelectric applications. Initially Tritt?s group has been and will continue to pursue studies of the low-dimensional pentatelluride materials: HfTe5 and ZrTe5. Tritt?s group will perform doping studies of the thermoelectric properties of these materials as well, which will include compounds such as Hf1-XZrXTe5. Subsequent doping studies on this family of compounds will include other substitutions, Hf1-XMXTe5-YZY, where M = Zr, Ta, Nb, Ti etc. and Z = S or Se. Tritt presented the preliminary results of the (Hf1-XZrXTe5) study at the XVI International Conference on Thermoelectrics in Dresden. Other promising low dimensional materials will also begin to be investigated.

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Search for Lower Temperature (T 100K)Thermoelectric Materials in the Pentatelluride System and other Low Dimensional Systems

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DAAG55-97-1-0267

6. AUTHOR(S)
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The views, opinions and/or findings contained in this report are those of the author(s) and should not be construed as an official Department of the Army position, policy or decision, unless so designated by other documentation.

12 a. DISTRIBUTION / AVAILABILITY STATEMENT
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12 b. DISTRIBUTION CODE

13. ABSTRACT (Maximum 200 words)
The main objective of the Clemson / DARPA project is to search for and achieve higher performance low temperature (100 K to 250 K) thermoelectric materials than exist to date. Dr. Tritt's group at Clemson University will perform synthesis and characterization of a number of low dimensional systems which show potential for use in thermoelectric applications. Initially Tritt's group has been and will continue to pursue studies of the low-dimensional pentatelluride materials: $HfTe_5$ and $ZrTe_5$. Tritt's group will perform doping studies of the thermoelectric properties of these materials as well, which will include compounds such as $Hf_{1-X}Zr_XTe_5$. Subsequent doping studies on this family of compounds will include other substitutions, $Hf_{1-X}M_XTe_{5-Y}Z_Y$, where M = Zr, Ta, Nb, Ti etc. and Z = S or Se. Tritt presented the preliminary results of the ($Hf_{1-X}Zr_XTe_5$) study at the XVI International Conference on Thermoelectrics in Dresden. Other promising low dimensional materials will also begin to be investigated.

14. SUBJECT TERMS
Thermoelectric materials, Low Temperature Thermoelectric cooling, Pentatelluride Materials, Low Dimensional Systems

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Enclosure 1

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The Report Documentation Page (RDP) is used for announcing and cataloging reports. It is important that this information be consistent with the rest of the report, particularly the cover and title page. Instructions for filling in each block of the form follow. It is important to ***stay within the lines*** to meet ***optical scanning requirements.***

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G - Grant	**TA** - Task
PE - Program Element	**WU** - Work Unit Accession No.

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REPORT DOCUMENTATION PAGE (SF298)
(Continuation Sheet)

Final Progress Report
5/15/97 thru 5/15/01 (DARPA / ARO)
DAAG55-97-1-0267
(Terry M. Tritt, PI, Clemson University)

Personnnel and Their Repsonsibilities Being Supported by Project

Dr. B. M. Zawilski (Postdoc until February 28, 2001):
Responsible for design, fabrication and calibration of new parallel thermal conductance (PTC) thermal conductivity measurement system. Performed initial measurements on a number of standards and pentatelluride materials.

Dr. D. Ketchum (Postdoc until December 2000):
Responsible for synthesis and structure chareacterization of pentatelluride series. Will perform necessary doping and solid state chemistry to advance project. Will perform initial measurements on low temperature structure.

Dr. Terry M. Tritt (Professor and PI): (3/4 summer month)
Responsible for oversight and direction of project, including determination of doping studies and new materials to investigate, oversight and management of personnel, oversight and responsibility of budget and purchases.
Laboratory manager and writing reports and manuscripts.

Dr. Joe Kolis (Co-PI, Chemistry): (3/4 summer month)
Responsible for oversight of project concerning chemistry, synthesis and characterization.
Oversight and supervision of Chemistry Postdoc

Dr. Matt Marone (Postdoc-one year): Responsible for design, fabrication and calibration of new thermal conductivity system. Performed initial measurements on materials.

Dr. C. R. Feger (Postdoc): Responsible for synthesis and structure chareacterization of pentatelluride series. Performed necessary doping and solid state chemistry to advance project. Will perform initial measurements on low temperature structure.

Personnnel and Their Repsonsibilities Being Supported by Project

Mr. R. T. Littleton (Graduate Student): (Full time support)
Responsible for measurements and characterization of electrical properties of all pentatelluride materials.
Design, fabrication and calibration of high temperature probe (80 K < T < 700 K)
(received Masters degree in Physics 8/98)
(received Ph.D student in MS&E at Clemson, May 2001)

Mr. Nathan Lowhorn (Graduate Student): (No support at this time)
Responsible for taking over the measurements and characterization of electrical properties of all pentatelluride materials.
(received Masters degree in Physics 8/00)
(currently Ph.D student in Physics at Clemson, degree expected Aug/Dec 2003)

Mr. Scotty Nicholson (Machine Shop Technician): (1/4 time) Repsonsible for machining and fabrication on thermal conductivity and Hall systems as well as other miscellaneous items.

Mr. Michael Long (Machine Shop Technician): (1/4 time) before Nicholson;
Repsonsible for machining and fabrication on thermal conductivity and Hall systems as well as other miscellaneous items.

Undergraduate Students:

Mr. John Cook, greaduated 2001. (3 summer months, P/T during semesters 2000)
Responsible for general lab duties, sample prep, etc.

Mr. Jason Jeffries, graduated:2000 (2 summer months, P/T during semesters 2000)
Responsible for general lab duties, sample prep,
Design, fabrication and calibration of high temperature probe (80 < T < 700K)

Mr. Raymond Tedstrom, graduated 2002: (2 summer months, P/T during semesters 2000)
Responsible for general lab duties, sample prep,
Design, fabrication and calibration of high temperature probe (80 < T < 700K)

Overall Program Objective

The main objective of the Clemson / DARPA-ARO project is to search for and achieve higher performance low temperature (100 K to 250 K) thermoelectric materials than exist to date. Clemson University will perform synthesis and characterization of a number of low dimensional systems, which show potential for use in thermoelectric applications. Low dimensional systems can lead to enhancement of the electronic properties over that of bulk materials. This research will be carried out within the Department of Physics and Department of Chemistry at Clemson University. Initially Clemson University will pursue studies of the low-dimensional pentatelluride materials: $HfTe_5$ and $ZrTe_5$. These materials show promise for potential low temperature thermoelectric applications. Low temperature thermoelectric materials in the 100 - 200 K range can open potential applications for certain IR detectors, especially the mid to far infrared detectors. If HgCdTe detectors could be thermoelectrically cooled and packaged then much faster response times and higher sensitivity could be achieved over current thermal imaging systems such as bolometers. Thermoelectric cooling to 100K would make the prospect of packaged superconducting electronics more achievable. Also, enhanced computing speed through “cold computing” can be achieved by cooling computer chips and electronics to temperatures in the 100 K to 250 K range.

A secondary objective was to develop state-of the art facilities for the characterization of the electrical and thermal properties of thermoelectric materials over a broad range of temperature and for various sample sizes. This will allow Clemson not only to pursue high quality measurements on its own samples but to serve as a measurement facility for the greater thermoelectrics community which were involved in the Darpa Thermoelectrics program.

Previous Plans for the final 8 months of project (completion date May 2001)

Materials and Doping Strategies:

Single crystals of the pentatelluride materials will continue to be grown via solid state synthesis in the Chemistry Department and characterized in the Physics Department for their potential for these low temperature (100 K - 250 K) applications in thermoelectric refrigeration. Clemson University will perform doping studies of the thermoelectric properties of these materials as well, which will include compounds such as Hf_{1-X} $Zr_XTe_{5-X}Se_X$ and Hf_{1-X} $Zr_XTe_{5-X}Sb_X$. More general doping studies on this family of compounds will include other substitutions, $Hf_{1-X}M_XTe_{5-Y}Z_Y$, where M = Zr, Ta, Nb, Ti etc. and Z = S, Se and Sb. In most cases small amounts of impurities including magnetic elements such as Fe, Co or Ni will be added. The addition of Bi into the structures will also be attempted as well as other broad range of doping strategies. In addition, we will pursue rare eart doping of these materials with the addition of Ce, La, Ho Eu etc. These studies will lead information important to optimize the electronic part of the figure of merit, ZT, for these materials. These materials will be characterized over a range of temperature from 350K to 20K in most cases.

In addition to the overall doping studies to investigate the optimal doping strategy we will also investigate synthesis routes to lead to much larger crystal sizes, with the overall goal crystals of approximately 1-2mm on a side and greater than 4mm in length. Since the larger crystal growth approach has proved fruitless so far, we have developed a new concept and approach to determine the absolute thermal conductivity which we call the parallel thermal conductance (PTC) technique. . Initial measurements of the thermal conductivity using our standard steady state techniques will begin and approaches such as alloy or magnetic scattering for the phonons will start to be employed towards minimizing the lattice thermal conductivity.

We will continue to investigate the thermal conductivity of these materials.

We have also identified a NaCoO system (a ceramic oxide) which we have been as a potential high temperature power generation applications.

Experimental and Capability Development:

Experimental capabilities continue to be developed and enhanced. The acquisition of the Quantum Design Physical Property Measurement System under DOD-DURIP (May 1998) has been a great addition to the lab. It allows magneto-transport and heat capacity measurements to be performed. We are planning to bring on-line a new electrical transport measurement system capable of measuring the Seebeck and electrical resistivity of two samples simultaneously as a function of temperature from $6 K < T < 320 K$. When this new system is operational our existing system will be reconfigured in the same way (however it is a 10 K limited system). We have also built a high temperature probe to cover a broader range in our characterization of materials. We redesigned our thermal conductivity system (PTC) to be able to increase our measurement capability. We will put together a Hall measurement system to investigate carrier concentration of these materials.

Accomplishments under this contract during the term of the contract (5/15/97 thru 5/15/01)

Single crystals of the "parent" pentatelluride materials $HfTe_5$ and $ZrTe_5$ have been synthesized as well as extensive doping of the other phases: , $(Hf_{1-X}Zr_XTe_{5-X}Y_X)$ (Y = Se, Sb). The thermoelectric power and resistivity have been measured on all the samples as a function of temperature from 320 K to 10 K.

We have had some substantial successes during the project period. These centered around substitutional doping of Sb and Se on the Te site in the $HfTe_5$ materials, $(Hf_{1-X}Zr_XTe_{5-X}Y_X)$ (Y = Se, Sb). The addition of small amounts of Sb resulted in totally suppressing the resistive anomaly in the pentatelluride materials. The resistivity is somewhat lower and has a metallic temperature dependence, resistivity decreasing with decreasing temperature. The relatively high thermopower values are maintained, S 100 μV/K at T 300K and decreasing with decreasing temperature. These results on the electronic properties exhibit power factor values greater than that of Bi_2Te_3 materials, over the temperature range of interest.

We continued the doping studies but the results of period warranted an intensive effort into measuring the thermal conductivity of these small ribbon-like single crystal materials. This is where we have focused our efforts over the two years of the project and with much success. We developed a new technique which we call the parallel thermal conductance (PTC) technique. The issue is that because of the size of these materials, it is very difficult for them to support a heater and the necessary thermocouples. The PTC technique allows us to bypass this problem. Briefly, the PTC technique uses a sample holder which has very low thermal conductance and the heaters and thermocouples are attached to this holder. The thermal conductance is measured of this "system" which gives the background thermal conductance when the sample is added in parallel. The background is then subtracted leaving the thermal conductance of the sample. There is still an issue concerning the resolution of the sample dimensions, which yield an uncertainty of 40-50 %. This technique was published in the Review of Scientific Instruments in 2001. The results on the thermal conductivity of the pentatellurides has been published in Appl. Phys. Lett. We have also published several papers on some of our novel measurement techniques and apparatus which can be found in the publications section.

The addition of small amounts of Se resulted in reducing the overall resistivity and enhancing or increasing the thermopower to values over 200 μV/K at T 100K. These are very large thermopower values at these temperatures in a system that is still a relatively good conductor. These effects resulted in power factor values greater than that of BiTe materials over the temperature range 100 K < T < 320K. This was especially the case in the range of interest T 150K. Initial determination of the thermal conductivity indicates that it is a factor of 2-3 times higher than desired. We are continuing the project with doping with heavy mass atoms to reduce the thermal conductivity.

Accomplishments under this contract during the term of the contract (5/15/97 thru 5/15/01) Cont.

A secondary objective of the project was to develop state-of the art facilities for the characterization of the electrical and thermal properties of thermoelectric materials over a broad range of temperature and for various sample sizes. This will allow Clemson not only to pursue high quality measurements on its own samples but to serve as a measurement facility for the greater thermoelectrics community which were involved in the Darpa Thermoelectrics program. We developed excellent facilities and participated in other Darpa related projects, such as the opals, the half-Huesler alloys and work on the skutterudites. Many of our novel measurement techniques and appartus were written up as scientific publications and published in review of Scientific Instruments, Cryogenics and the MRS Proceedings.

Final Progress Report
5/15/97 thru 5/15/01 (DARPA / ARO)
DAAG55-97-1-0267
(Terry M. Tritt, PI, Clemson University)

CLEMSON GROUP PRODUCTIVITY ON
ARO/DARPA Grant # DAAG55-97-1-0267
1/1/00 THRU 12/31/00

PATENTS SUBMITTED:

- Transition Metal Pentatellurides and Transition Metal Chalcogenide Compounds for Potential Thermoelectric Materials: **Terry M. Tritt**, **(PI)**
  Terry M. Tritt, **(PI)**
  submitted to University committee Oct 15 1997
  approved for further action-November 24, 1997
  action by lawyers to file August 1998, Dec 2000. May 2002

Editorials:

* 2000 ***Semimetals and Semiconductors*** (3 Volumes: Volume **69, 70** and **71**)
  Thermoelectric Materials - Current Trends and Approaches
  Editor **Terry M. Tritt,** Academic Press

  Volume 69: *Thermoelectric Materials – Recent Developments in Thermoelectric Materials: Bulk Materials and Overview – Part I*

  Volume 70: *Thermoelectric Materials – Recent Developments in Thermoelectric Materials: Bulk Materials and Overview – Part II*

  Volume 71: *Thermoelectric Materials – Recent Developments in Thermoelectric Materials: Thin Film and Superlattice Materials – Part III*

* Proceedings of 2000 Materials Research Society **Volume 626**
  New Materials for Small Scale Thermoelectric Refrigeration and Power Generation

  Applications,
  Edited by **Terry M. Tritt,** G. Nolas, M. Kanatzidis, G. Mahan and D. Mandrus

Review Articles:

* 1999 Annual Review of Materials Science:
Skutterudites: A Phonon-Glass-Electron-Crystals Approach To Advanced Thermoelectric Materials Research.by: G. Nolas , D. Morelli and **T. M. Tritt**
Annual Review of Materials Science, **29**, 89-116, 1999

* 2000 ***Semimetals and Semiconductors*** (Volume **69**)
Overview of Measurement and Characterization Techniques for Thermoelectric Materials: pp. 25-50
Terry M. Tritt and Valerie M. Browning

* 2000 ***Semimetals and Semiconductors*** (Volume **70**)
Thermoelectric Properties of Quasicrystals
pp. 77 - 116
Terry M. Tritt, A. L. Pope and Joseph W. Kolis

* 2000 ***Semimetals and Semiconductors*** (Volume **70**)
Thermoelectric Properties of Transition Metal Pentatellurides
pp. 179-206
Terry M. Tritt and Roy T. Littleton, IV **Conference Executive Participation:**

* Proceedings of 2000 Materials Research Society **Volume 626**
New Materials for Small Scale Thermoelectric Refrigeration and Power Generation Applications,
Edited by **Terry M. Tritt,** G. Nolas, M. Kanatzidis, G. Mahan and D. Mandrus

Conference Organizer
Conference Budget Officer

* 1999-2002 International Thermoelectrics Society: **T. M. Tritt,** Executive Board

INVITED PRESENTATIONS (1997 –2001 related to project or TE's):

- *Measurement and Characterization of Thermoelectric Materials.*
  Terry M. Tritt,
  1997 Materials Research Society, Spring March 31-April 4th (San Francisco)
  Symposium Q: Thermoelectric Materials, New Directions and Approaches
  p 290, 1997 Spring MRS Meeting Abstracts, April 1997

- *Thermoelectric Properties of the Pentatelluride Materials*
  $Hf_{1-X}M_XTe_5$ (M = Zr, Ti, Ta and Nb).
  Terry M. Tritt, DARPA Review on Thermoelectric Materials Program
  August 11& 12, 1997, Pasedena CA

- *Low Temperature Thermoelectric Materials for Small Scale Refrigeration Applications*.
  Terry M. Tritt, October 23, 1998
  ICSICT-98 (Solid State and Integrated Circuit Technology) Bejing China

- *Thermoelectric Materials for Small Scale Refrigeration and Power Generation Applications.*
  Terry M. Tritt, Senate Liason to Armed Forces Committee
  Clemson University, Clemson SC, December 16, 1997

- *Thermoelectric Materials for Automotive Applications*
  Terry M. Tritt,
  Automotive Resarch Opportunities at Clemson University
  BMW Vice President George West
  Clemson University, Clemson SC, December, 1997

- *Thermoelectric Materials for Small Scale Refrigeration and Power Generation Applications.*
  Terry M. Tritt, Davidson College Evening Seminar Series
  Davidson NC, February 17, 1998

- *Thermoelectric Properties of the Pentatelluride Materials*
  $Hf_{1-X}M_XTe_5$ (M = Zr, Ti, Ta and Nb).
  Terry M. Tritt, Bejing (had to be withdrawn due to travel constraints)
  International Conference on Integrated Electronics (ICSICT '98)

- *Low Temperature Thermoelectric Materials for Small Scale Refrigeration Applications*.
  Terry M. Tritt, October 23, 1998
  ICSICT-98 (Solid State and Integrated Circuit Technology) Bejing China
  Had to be withdrawn due to travel constraints

- *Thermoelectric Materials for Small Scale Refrigeration and Power Generation Applications.*
  Terry M. Tritt, Ames National Lab and Iowa State University
  Ames Iowa, September 11, 1998

- *Thermoelectric Materials for Small Scale Refrigeration and Power Generation Applications.*
  Terry M. Tritt, Michigan State University,
  Condensed Matter Physics Seminar
  East Lansing Michigan, September 14, 1998

- *Thermoelectric Materials for Small Scale Refrigeration and Power Generation Applications.*
  Terry M. Tritt, University of Michigan,
  Condensed Matter Physics Seminar
  Ann Arbor Michigan, September 15, 1998

- *Thermoelectric Materials for Small Scale Refrigeration and Power Generation Applications.*
  Terry M. Tritt, University of Virginia,
  Condensed Matter Physics Seminar
  Charlottesville VA, October 23, 1998

- *Thermoelectric Materials Run Hot and Cold*
  Terry M. Tritt, University of Virginia,
  Society of Physics Students Seminar
  Charlottesville VA, October 23, 1998

- *Transport Properties Of Group IV Metal Tellurides: Possible Low Temperature Thermoelectrics.*
  Joseph W. Kolis*, Christopher Feger., **Terry M. Tritt**, Roy Littleton IV,
  1998 Fall MRS Meeting, Symposium Z, *New Materials for Small Scale Thermoelectric Refrigeration and Power Generation Applications*,
  editors: T. M. Tritt, M. Kanazidis, G. Mahan and H. B. Lyons, Jr.

- *Thermoelectric Materials for Small Scale Refrigeration and Power Generation Applications.*
  Terry M. Tritt, Oak Ridge National Laboratory,
  Condensed Matter Physics Seminar
  Oak Ridge , Tenn., January 15, 1999

- *Thermoelectric Materials for Small Scale Refrigeration and Power Generation Applications*.
  Terry M. Tritt, University of South Carolina,
  Condensed Matter Physics Seminar
  Columbia, SC, January 21, 1999

- *Thermoelectric Materials for Small Scale Refrigeration and Power Generation Applications.*
  Terry M. Tritt, University of Idaho,
  Condensed Matter Physics Seminar
  Moscow ID, Feb. 2, 1999

- *Thermoelectric Materials for Small Scale Refrigeration and Power Generation Applications.*
  Terry M. Tritt, University of Oregon,
  Condensed Matter Physics Seminar
  Eugene, OR, February 5, 1999

- *Thermoelectric Materials for Small Scale Refrigeration and Power Generation Applications.*
  Terry M. Tritt, Allied Signal,
  Condensed Matter Physics Seminar
  Morristown, NJ, February 17, 1999

- *AOP Regional Science Fair Awards Ceremony:* **Keynote Address**
  Terry M. Tritt, CoES,
  Clemson University, March 24, 1999

- *Research and Investigations of New and Novel Materials for Thermoelectric Applications.*
  Terry M. Tritt, CoES College Advisory Board,
  Clemson University, Clemson SC, April 23, 1999

- *Research and Investigations of New and Novel Materials for Automotive Applications.*
  Terry M. Tritt, BMW Corporation,
  Clemson University, May 5, 1999

- *DARPA DSRC Special Panel on Potential Applications of Nanostructured Materials Thermoelectric Materials.*
  Terry M. Tritt,
  Washington D.C. May 19, 1999

- *Investigation of Novel and Advanced Materials*
  Terry M. Tritt,
  1999 Summer Science Research Institute
  Clemson University, Clemson SC, July 20, 1999

- *Investigation of Novel and Advanced Materials*
  Terry M. Tritt,
  Clemson University Research Foundation
  Clemson University, Clemson SC, September 10, 1999

- *Thermoelectric Materials for Small Scale Refrigeration and Power Generation Applications.*
  Terry M. Tritt,
  Condensed Matter Physics Seminar
  Auburn University, Auburn, AL, October 22, 1999

- *The Next Generation Thermoelectric Materials,*
  Terry M. Tritt,
  (Special Invited Session on Thermoelectric Materials)
  Bull. Am. Phys. Soc., **Vol 44,** , 26, SESAPS-99,
  Chapel Hill, NC Nov 7-9, 1999

- *Introduction to Thermoelectric Materials*
  Terry M. Tritt,
  Special Dept. of Energy Workshop on
  Future Directions in Thermoelectric Materials Research
  Oak Ridge National Laboratory,
  Oak Ridge, Tenn., January 10 & 11, 2000

- *The Next Generation Thermoelectric Materials Under Investigation at Clemson University*
  Terry M. Tritt,
  Special Dept. of Energy Workshop on
  Future Directions in Thermoelectric Materials Research
  Oak Ridge National Laboratory,
  Oak Ridge, Tenn., January 10 & 11, 2000

- *Electrical and Thermal Thermal Transport Rapid Measurement Equipment Using a Cryocooler Based Cooling System.*
  Terry M. Tritt and **Roy T. Littleton, IV,**
  Quantum Design
  San Diego, CA, January 14, 2000

- *Strategies for the Investigation of New Bulk Materials for Thermoelectric Applications*
  Terry M. Tritt, A.L.Pope, R. T. Littleton, IV, S.Bhattacharya, M. Kaeser, S.J.Poon, J. W. Kolis, G. S. Nolas, J. S. Olson, V. Ponnambalam, and Y.Xia
  Invited Plenary talk at ICT-2000 (August 2000)

- *Effects of various Grain structure and Sizes on the Thermal Conductivity of Ti-based Half-Heusler alloys*
  Terry M.Tritt, S.Bhattacharya, Y.Xia, V. Ponnambalam, S.J.Poon and N. Thadhani
  Invited Plenary talk at ICT-2001, (June 8-11, 2001)

PUBLICATIONS AND PROCEEDINGS:

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  Terry M. Tritt
  2001 Fall MRS Meeting, Symposium G, *Thermoelectric Materials,*
  editors: G. S. Nolas, D. Mandrus and D. Johnson
  MRS Fall 2001 Symposium G: **(# G1-1)**.

- *Raman scattering in Sb doped Transition Metal pentatellurides* $ZrTe_{5-x}Sb_x$
  K. McGuire, Nathan D. Lowhorn, T. M. Tritt and A. M. Rao
  2001 Fall MRS Meeting, Symposium G, *Thermoelectric Materials*,
  editors: G. S. Nolas, D. Mandrus and D. Johnson
  MRS Fall 2001 Symposium G: **(# G5-3)**

- *Transformation of Multiwalled Carbon Nanotube into Strings of Carbon Nanoshells*
  B. Sadanadan, J. Gaillard, T. Savage, S. Bhattacharya, **T. M. Tritt**,
  and A. M. Rao et. al.
  2001 Fall MRS Meeting, Symposium Z, *Making Functional Materials with Nanotubes,*
  editors: P. Bernier,P. A. Ajayan, Y. Iwasa and P. Nikolaev
  MRS Fall 2001 Symposium Z: (# Z6-18)

- *Effects of various Grain structure and Sizes on the Thermal Conductivity of Ti-based Half-Heusler alloys*
  S. Bhattacharya, **Terry M.Tritt,** Y.Xia, V. Ponnambalam, S.J.Poon
  and N. Thadhani
  Ga. Tech. Conferenence on Nanomaterials and Nanotechnology, (Sept. 2001)

Enclosure 2

MEMORANDUM OF TRANSMITTAL

U.S. Army Research Office
ATTN: AMXRO-ICA (Ms. Sandra Yates)
P.O. Box 12211
Research Triangle Park, NC 27709-2211

Enclosure 2

MASTER COPY: PLEASE KEEP THIS "MEMORANDUM OF TRANSMITTAL" BLANK FOR REPRODUCTION PURPOSES. WHEN REPORTS ARE GENERATED UNDER THE ARO SPONSORSHIP, FORWARD A COMPLETED COPY OF THIS FORM WITH EACH REPORT SHIPMENT TO THE ARO. THIS WILL ASSURE PROPER IDENTIFICATION. NOT TO BE USED FOR INTERIM PROGRESS REPORTS; SEE PAGE 2 FOR INTERIM PROGRESS REPORT INSTRUCTIONS.

MEMORANDUM OF TRANSMITTAL

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* ☐ Reprint (Orig + 2 copies)

X☐ Technical Report (Orig + 2 copies)

☐ Manuscript (1 copy)

☐ Final Progress Report (Orig + 2 copies)

☐ Related Materials, Abstracts, Theses (1 copy)

35.) A complete set of reprints subject to ARO support will be submitted with the final report
36.)

CONTRACT/GRANT NUMBER: DAAG55-97-1-0267

REPORT TITLE: Search for Lower Temperature (T 100K)Thermoelectric Materials in the Pentatelluride System and other Low Dimensional Systems

is forwarded for your information.

SUBMITTED FOR PUBLICATION TO (applicable only if report is manuscript):

Sincerely,
Terry M. Tritt
Dept. of Physics
Clemson University

Enclosure 3

FORECAST EXPENDITURE REPORT
(IMPORTANT!>>>YOU MUST REPLY TO RECEIVE ADDITIONAL FUNDING<<<)

The research agreement identified below is under consideration for additional funding. The contemplated funding, resulting in an extension to the performance period of the agreement, is consistent with the terms and conditions of the agreement. Before a decision can be made to provide the additional funding, the following information is needed: (i) an accounting of costs incurred to date and (ii) a projection of financial needs for the period of the agreement extension. Please complete SECTION 2, below **within 30 days of receipt of this request** and return to: U.S. Army Research Office, ATTN: (Name provided by ARO) P.O. Box 12211, Research Triangle Park, North Carolina, 27709-2211.

SECTION 1: GENERAL INFORMATION – Provided by ARO

ARO Proposal Number: (Provided by ARO)
Agreement Number: (Provided by ARO)
Agreement Period: From - To (Provided by ARO)
Recipient: (Provided by ARO)
Principal Investigator: (Provided by ARO)
ARO Technical Monitor: (Provided by ARO)
ARO Technical Monitor's E-mail: (Provided by ARO)

Total Anticipated Award: ($ Provided by ARO)
Amount Funded to Date: ($ Provided by ARO)
Currently Funded Through: (Provided by ARO)
Planned Funding: (Provided by ARO)
Planned Extension Funding: (Provided by ARO)
Monitor's Phone #: (Provided by ARO)

SECTION 2: ACCOUNTING AND FORECASTING OR EXPENDITURES – Completed by PI

1. Expenditures (cost incurrences from date of contract/grant initiation) as of date of receipt of this request or as of most recent cut-off in accounting records: $__ $911,708
2. Additional projected expenditures before (date entered by ARO): $________0________
3. Total of items 1 and 2: $_________________
4. Forecast expenditures for the proposed (number) months period of extension: $_______*
5. The **required annual Interim Progress Report** covering the previous calendar year was submitted on __5/24/01________. Detailed instructions can be found in the Reporting Instructions Section of the ARO Home Page at http://www.aro.army.mil.

Date:____5/22/02__________________

Signature___Terry M. Tritt__
Principal Investigator

***** The forecast cannot exceed the planned level of funding identified in SECTION 1. If the forecast expenditures differ significantly from the budget previously negotiated and included in the research agreement, a new budget must be submitted. A "significantly different" budget is defined as (i) a decrease in the planned funding level cited above or (ii) a deviation of 10% (plus or minus) to any cost element (direct labor, indirect expense, travel, etc.) included in the budget.

SECTION 3: FOR U.S. ARMY RESEARCH OFFICE USE ONLY – Completed by TM

____Recommend funding at level cited in SECTION 1, above.

____Recommend no additional funds be provided at this time.

____Recommend funding consistent with revised budget of principal investigator.

____Recommend extension of agreement through_________without additional funds.

____Recommend funding in amount of $__________ (Comments attached)

____Other (Explanation attached).

Date:_______________________

Signature___________________________
Technical Monitor

Enclosure 4