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THERMOELECTRICS IN INDIAN SCENARIO

Controlling simultaneously the electric and thermal properties of materials can lead to very efficient thermoelectric devices. In thermoelectric materials, the application of a temperature gradient generates a voltage, and vice versa. By exploiting this coupling between thermal and electrical properties, devices can be made that carry heat from a cold side to a hot side or that generate electricity from heat flows. Ensuring a sustainable energy supply is one of the grand challenges for science and technology in the 21st century. There is an urgent need for improved ways of generating power, without heavy reliance on fossil fuels. Thermoelectric devices, which exploit the Seebeck effect to provide direct thermal into electrical energy conversion, offer considerable attractions for a more efficient use of existing energy resources. In particular, thermoelectric power generation enables useful electrical power to be extracted from waste heat. However, the performance, cost and availability of thermoelectric materials are significant barriers to the broad implementation of thermoelectric technology. Commercial thermoelectric devices are still largely based on bismuth telluride alloys, and their thermoelectric figure of merit, combined with the scarcity of tellurium, limit these devices to niche applications. For these reasons, research in thermoelectric materials is very active worldwide, with the field rapidly advancing into entirely new classes of materials. This encompasses not only a wide range of inorganic materials, but also organic molecules and polymers. Advances following different routes were highlighted in this study.

Key words: Peltier Effect, Thermoelectric Cooling Helmet, Computational fluid dynamics, heat transfer, heat pipe, volume flow rate, Pressure drop.

Introduction

Thermoelectric Advancement under the aegis of MECON: R&D Division of MECON LTD., Ranchi has done extensive work on thermoelectrics since the last 30 years. The present work is the synopsis of the previous work done and advancement achieved in thermoelectric field [1 – 10].

Solid State Microclimate Conditioning Unit for Defence Personnel

Solid state microclimate conditioning unit was successfully designed, developed and demonstrated for defence personnel working at high ambient temperature or at desert.

The cooling unit was integrated in MBT ARJUN TANK and successfully demonstrated at CVRDE, Avadi. Final demonstration trials of such solid state cooling unit were conducted at Mahajan Field Firing Range at Rajasthan (**Indo-Pak Border) in June 2005 [11].** The project was sponsored by DIPAS, (DRDO), Delhi.

Anti-Tank Missile

A critical problem on anti-tank missile was assigned by DRDL, (DRDO) Hyderabad to MECON. The project was completed successfully and well accepted by DRDL. The project was funded by DRDL, DRDO Hyderabad and completed in the year 2004. Implementing agency was Indian army [12 – 13].

Heating Gloves and Socks for Defence Personnel

MECON has successfully designed and developed battery operated heating gloves and socks for Defence Personnel working at sub-zero environment. The project was funded by DIPAS, (DRDO), Delhi. The project was implemented in Defence (Kargil, Leh) and completed in the year 2006.

Thermoelectric Cold Chain Chest Operated by 12 V DC Vehicular battery

Thermoelectric cold chain chests developed by MECON are suitable for use in medical and health-care programs for storing and / or transporting medicines, drugs, vaccines, serum, semen diagnostic materials for urban as well as rural areas. The project was funded by DST, Delhi. Implementing agency was AIIMS and was completed in the year 2003 [14 – 15].

Thermoelectric Cooling/Heating Helmet

Three types of cooling/heating helmets were developed that are distinct in terms of process of development, usability, and feasibility in industrial premises.

A. Direct cooling/heating helmet.

B. Back pack cooling/heating helmet.

C. Trolley based cooling/heating helmet.

A. Direct Cooling/Heating Helmet

The helmet is fitted with TE module and conventional heat sink. Cooling is by conduction and the heat sink is of convective type. The cold side of the module is in contact with perforated aluminum sheet inside the helmet. Head cooling is by conduction over the cold aluminum sheet towards the head. Rechargeable battery pack and electrical switch is fixed with waist belt. The helmet is constructed based on a fiber-glass shell, provided with a heat distribution surface internally, which is separated from the fiberglass shell surface by a layer of insulation. The external and internal surfaces of the fibre-glass shell are insulated leaving openings for the extraction of heat from the inner surface through the thermoelectric module units thermally bonded to the inner conducting layer. Thermoelectric modules are thermally connected with the inner heat distribution surface. Each thermoelectric module is thermally connected to an external heat sink and such heat sink has an inbuilt fan, thus enabling the thermoelectric device to extract heat from the inner heat distribution surface, when electrically powered.

The heat distribution surface is cooled at multiple points, as equidistant as possible, thus optimizing the temperature changes in linear directions away from the cold spot. The heat distribution surface envelops the major part of the surface of the head and effectively creates a common air volume which enables the surface of the head to experience the same environment as created by the operation of the thermoelectric modules for the whole surface, uniformly. Thus the external heat sinks are oriented with respect to the helmet surface such that the air-flows are independent and non-interfering [16].

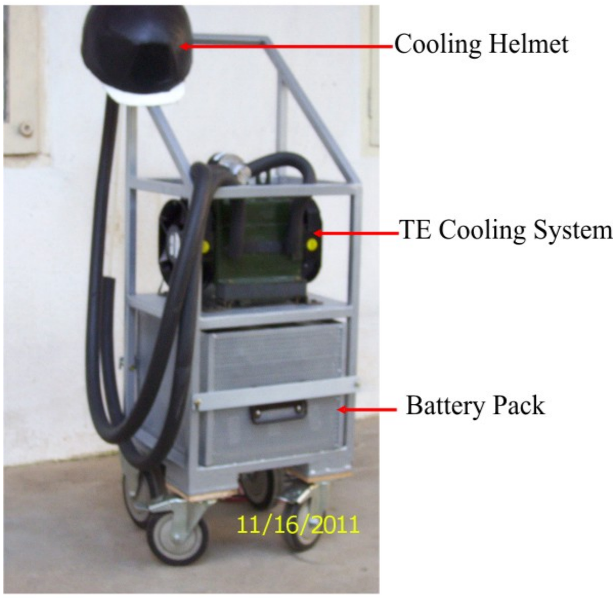
B. Back Pack Cooling/Heating Helmet

It is basically circulating dry & cold air underneath the head to keep the person dry which, in a sense, will keep him cool even on hot environmental condition. The system extracts around 80 Watts of metabolic heat from human head at an ambient of 55°C. Our cooling system is made of hybrid heat sink (convective and heat pipe both) with thermoelectric modules, small fans, blower and rechargeable

battery to be carried as back pack. Heat sink assembly has components like inlet duct (divergent), cold plate, outlet duct (convergent), TE modules, aluminum block, heat pipe, fins, and fan as shown in figure below. Hot ambient air is forced to flow through cold plate by blower. Blowers are DC radial type designed to generate enough pressure drops to make flow through the cold plate. Divergent and convergent ducts guide the flow through cold plate. Cold
plate has several baffles which retards the flow and helps in heat transfer. Hot side fan is used to facilitate forced convection heat transfer from hot side fins. Volume flow rate for fan was investigated for desired design performance. Heat dissipated from the hot side of TE modules is transferred to heat pipe through aluminum block. It is assumed that there is no heat loss (convection and conduction) from aluminum block and hot side TEM temperature is taken as input to heat pipe. Increasing the length of heat pipe & keeping the number of fins same would not have any impact on heat dissipation quality of hot side assembly. However, with introduction of a greater number of fins on the heat pipe, an improvement in heat dissipation is possible [17].

C. Trolley Based Cooling/Heating Helmet

This unit is a thermo mechanical assembly of a heat pump (the thermoelectric modules), heat sinks, spacer and cold plates that work on thermoelectric Peltier principle in which water is used to accumulate and transfer heat in the cooling system. The cold water through the narrow tube absorbs the metabolic heat of the head and transfers the same to the cold chamber, which is again cooled by the TE module. The cold face of the module is in contact with the cold chamber filled with water. The hot side of the module is in contact with the heat sink through which the heat generated in the hot surface of the module is dissipated. Fans are used for force dissipation of heat. The quicker the hot surface heat will be removed, the quicker the cold face temperature will come down.

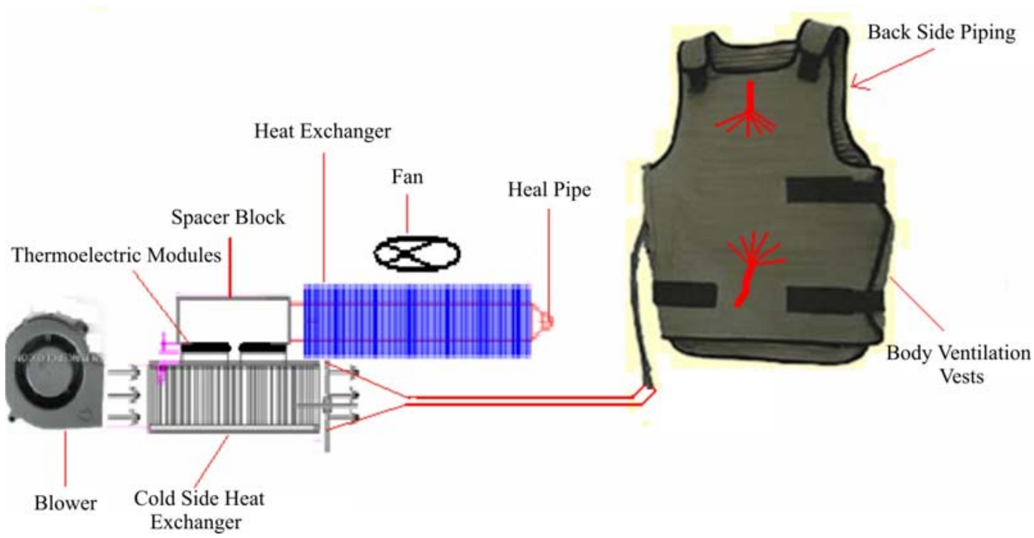


Thermoelectric Filter

MECON's in house Research and Development Division has successfully developed the system and applied for its Indian Patent to overcome cold starting problem in automobiles arising due to extremely low temperature by using thermoelectric in conjunction with a thermal storage device. The thermal storage device acts like a heat reservoir and thermoelectric modules acting as heat pumps extract heat from the thermal storage device and pump it to the filter thereby enabling quick starting of the automobiles in cold environments. It has been experimentally proved that an automobile can be started within 100 seconds using proposed device. [18]

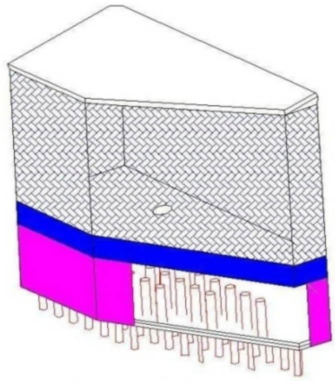
Air Warrior Body Ventilation Vest for Defence Personnel

Air warrior body ventilation vest is a light weight, comfortable, breathable, tube type undergarment worn against the skin. It provides cooling to circulate a coolant dry air to the torso of body to remove metabolic heat from personnel working in heat stress environments. The system requires extracting around 80 to 90 Watts of metabolic heat from human body at an ambient of 55 ^{o}C, which will be operated by portable blower & rechargeable battery [19].



Solid State Cooling Drinking Water Tank for Armoured Vehicles

During the journey to war field; it is an acute problem for the soldier for getting comfortable cold drinking water, especially during summer. Generally after three hours soldiers used to take warm water for drinking purpose and due to this the physiological parameters of human body go from bad to worse. Similarly, for cooking their food, they were unable to get warm or hot water during their war field. Such warm or hot water they may like to use for preparing their meals ready to eat. Hence; keeping this in mind; design of solid state water cooler/heater for Army personnel by considering all the boundary condition given for respective Armoured Vehicles. By using solid state cooling/heating concept is going to use to cool or heat the water of Armoured Vehicles, which can be operated by DC power supply (mainly by their back-up battery system), Voltage ranging from 20 V DC to 28 V DC during their war field. The power consumption from DC power supply depends on the parameters like ambient temperature, supplied voltage & amount of heat to be extracted or to be thrown [20].

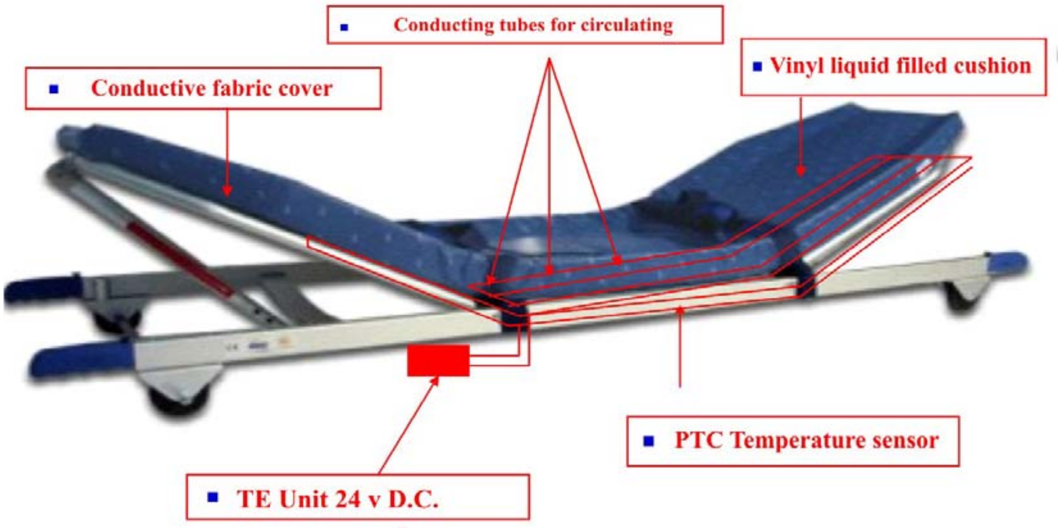


Thermoelectric stretcher

Thermoelectric heated / cooled wheeled stretcher mainly consists of two parts:

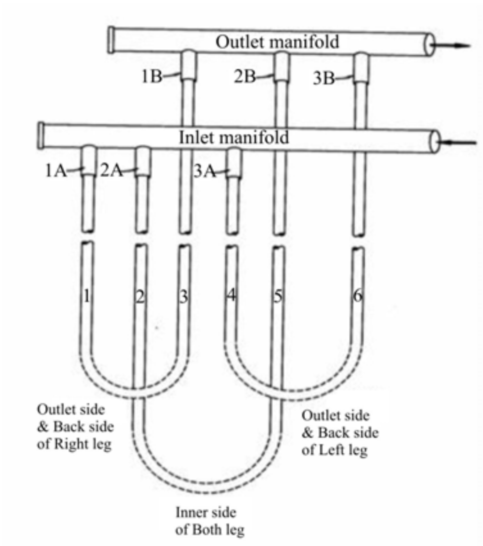
Part – 1 Consists of a stretcher made of series & parallel connection of conducting tubes to circulate hot or cold fluids across the stretcher to prevent soldiers from casualty.

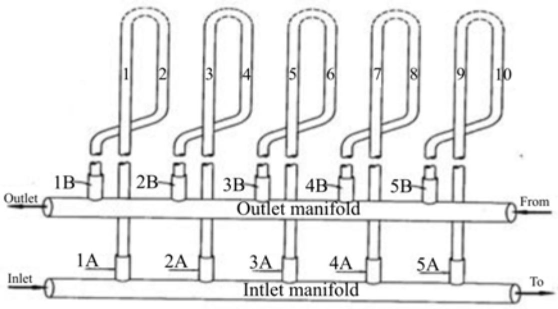
Part – 2 Consists of thermoelectrically cooling / heating unit, which is a thermomechanical assembly of heat pump, i.e. thermoelectric modules, heat & cold sinks, one positive displacement pump and one axial fan to dissipate heat from the system. This thermoelectric stretcher will provide adequate heating or cooling to the soldier depending upon their requirements by changing the polarity of thermoelectric array.

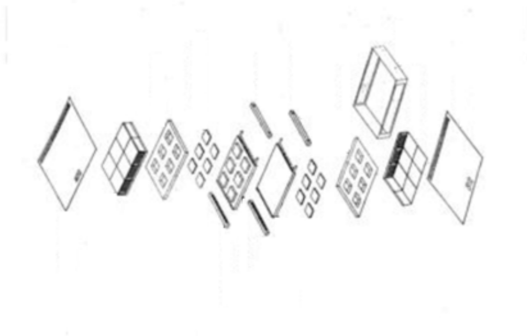


The cooling & heating system, employing this technology are solid state and CFC free devices. They are highly reliable and easily maintainable devices. Performance of the system has been ensured by our innovating design, assembly, made possible by software developed from our mathematical modelling. Thermal impedance matching of all the components of the unit treated as discrete thermal models with discrete characteristics has been ensured. Liquid cooling stretcher is used to absorb the excess metabolic heat from the body using thermoelectrically chilled fluid, such as water. In this unit cooling is transferred by conduction through PVC tubes carrying cooling medium. The cooling medium absorbs the metabolic heat energy and flows to the thermoelectric cooling unit which transfers the heat energy therefrom. Thus the system operates in a closed loop.

The unit is a thermo mechanical assembly of heat pump (the thermoelectric modules), heat sinks, spacers and cold plates. The thermoelectric modules are sandwiched between the heat sinks on the one side, and the spacers and cold plate on the other side. Each cold plate is in turn sandwiched between two sub assemblies. Each of these subassemblies is made up of a set of thermoelectric modules, heat sinks and spacers. A number of sandwich assemblies can be stacked together to remove the required amount of heat from water flowing through the cold plate. A suitable pump is used to make water flow through the cold plate in tandem, or parallel as required. The cold plate has a spiral hole with obstructions in the flow path, to provide maximum heat transfer area, as well as turbulence in flow. Fans are mounted (if required) at suitable locations to carry the heat away from the heat sinks efficiently. The heat sinks have the optimum design of fins, to provide maximum area of heat transfer.





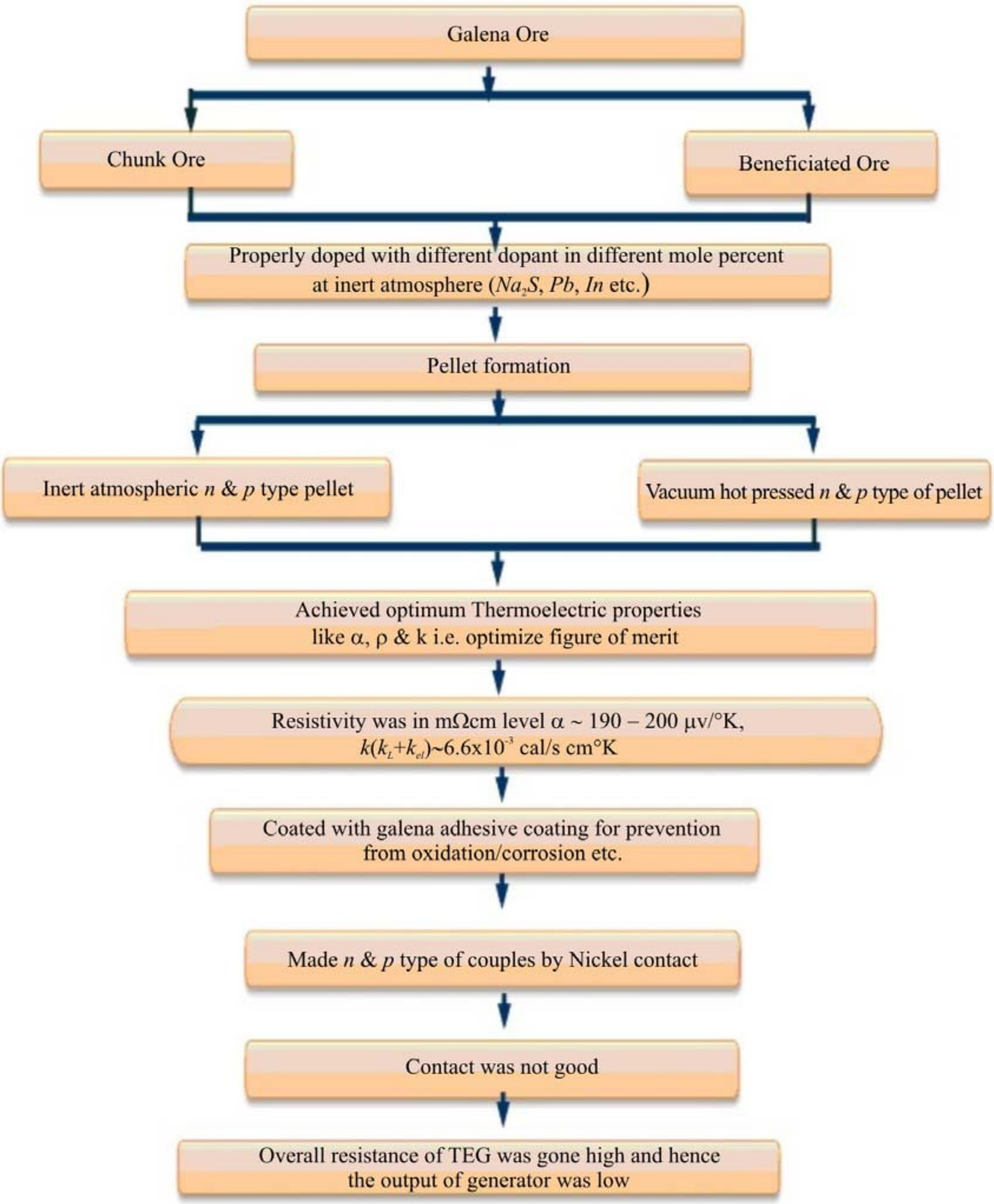


Galena Thermoelectric Generator [21 – 26]

Beneficiated Ore **Pellets**

Chunk Ore

Thermoelectric Generator



Thermoelectrics in Indian Scenario other than MECON

Dr. Chandra Mohan Bhandari from the University of Allahabad has done the following successful research in the thermoelectric domain:

Thermal conductivity of *Ge-Si* alloys at high temperature, Role of longitudinal and transverse phonons in lattice thermal conductivity of *GaAs* and *InSb*, Temperature dependence of density-of-states effective mass and electronic and phonon contributions to thermal resistance of doped *Si-Ge* alloys at high temperatures, influence of point defects on phonon drag thermoelectric power, magnon drag thermoelectric power, thermal conductivity of highly disordered semiconductor alloys, effect of grain size on the thermoelectric conversion efficiency of semiconductor alloys at high temperature, the generalization of Callaway thermal conductivity equation, theoretical analysis of thermoelectric figure of merit, temperature dependence of the figure-of-merit of improved thermoelectric materials based upon lead telluride, lattice thermal conductivity of small-grain-size *Pb-SnTe* and *Pb-GeTe* thermoelectric material, electronic contribution to the thermal conductivity of narrow band gap semiconductors: effect of non-parabolicity of bands. Towards a thermal conductivity minimum: thermoelectric considerations, solid solubility in thermoelectric semiconductors, Seebeck coefficient and electrical conductivity of *Si-Ge* alloys, phonon drag thermoelectric power in copper alloys, fine grained *Si-Ge* alloys as superior thermoelectric materials, electronic thermal transport in thermoelectric material effect of band nonparabolicity, thermoelectric behaviour of multivalley semiconductors, minority carrier effects on the thermoelectric figure-of-merit, preparation and thermoelectric properties of improved *PbSnTe* alloys [27 – 30].

Dr. Ramesh Chandra Mallik, from IISC Bangalore has done the following successful research in the thermoelectric domain:

Ball Mill Synthesis of bulk quaternary $Cu_2ZnSnSe_4$ and thermoelectric studies, thermoelectric properties of *In*- and *I*- doped *PbTe*, *Sn*-doped *BiCuSeO*, *Bi*-doped tetrahedrite, *Cd*-doped tetrahedrite, *In*-doped $Cu_2CdSnSe_4$, *PbTe* with Indium and Bismuth secondary phase, *Co* substituted synthetic tetrahedrite; synergistic combination of atomic scale structural engineering and panoscopic approach in *p*-type *ZrCoSb*-based half-Heusler thermoelectric materials for high ZT, thermoelectric materials for sensor applications, *In*-doped multifilled *n*-type skutterudites, thermoelectric properties of *Mn* substituted synthetic tetrahedrite, improvement of electrical conductivity in $Pb_{1-y}Sn_yTe$ alloys doped with manganese for high temperature thermoelectric applications, nanostructuring of *p*- and *n*-type skutterudites reaching figures of merit of approximately 1.3 and 1.6, respectively, thermoelectric properties of indium doped $PbTe_{1-y}Se_y$ alloys, Cu_2GeSe_3, *Zn* doped Cu_2SnSe_3, two-phase *PbTe* with Indium inclusions, $Fe_{0.2}Co_{3.8}Sb_{12-x}Te_x$ skutterudites, chalcogenide based $Cu_{2.1}Zn_{0.9}Sn_{1-x}In_xSe_4$ ($0 = x = 0.1$), thermoelectric properties of *PbTe* with encapsulated bismuth secondary phase, *Bi*-added Co_4Sb_{12} skutterudites, chalcogenide based $Cu_{2+x}ZnSn_{1-x}Se_4$, Indium filled and Germanium doped Co_4Sb_{12} skutterudites and examination of thermoelectric properties of other materials too has been done [31 – 35].

Dr. Ravi Kumarn from IIT Madras has done following successful research in the thermoelectric domain:

Thermodynamic modelling of *Ti-Zr-N* system, thermal conductivity of precursor derived *Si-B-C-N* ceramic foams using Metroxylon sagu as sacrificial template.

Prof. Tapas De from IIT Kharagpur has done the following successful research in the thermoelectric domain:

Thermal conductivity and viscosity of Al_2O_3 nanofluid based on car engine coolant. Investigation of thermal conductivity, viscosity, and electrical conductivity of graphene based nanofluids. Thermophysical and pool boiling characteristics of *ZnO*-ethylene glycol nanofluids. Investigations on the pool boiling heat transfer and critical heat flux of *ZnO*-ethylene glycol nanofluids. Thermal properties of silicon powder filled high-density polyethylene composites. Role of interfacial layer and clustering on the effective thermal conductivity of *CuO*-gear oil nanofluids. Excess electrical conductivity and thermoelectric power of (YBa_2Cu_3. 05Ox) Agn pellets. Temperature dependence of the thermoelectric power of $La_{1-x}K_xMnO_3$ compounds in light of a two phase model. Thermoelectric power of undoped and doped *Y-Ba-Cu-O* superconductor between 77 and 300 K. Temperature dependence of electrical conductivity and thermoelectric power of *Bi-Sb* tapes prepared by liquid quenching. Thermoelectric power of deoxygenated Bi_1 $6Pb_0$ $4Sr_2Ca_2Cu_3O_{10+\delta}$ sintered superconducting pellets. Thermoelectric power of samarium substituted $Y_{1-x}Sm_x$ $Ba_2Cu_3O_{7-\delta}$ superconducting pellets. Thermal conductivity of (2223) *Bi-Pb* cuprate superconductors: influence of doping and heat treatment time [36 – 41].

Dr. U.V. Varadaraju from IIT Madras has done the following successful research in the thermoelectric field:

Thermoanalytical investigations on the sol-gel synthesis of $YBa_2Cu_3Ov_7$. Thermodynamic stabilities of ternary oxides in the *Ba-Pb-O* system by the e.m.f. technique. High-temperature resistivity and thermopower studies on substituted *Bi*-2212 and *Bi*-2201 systems. Thermoanalytical investigation of the formation of $YBa_2Cu_{3\ \mathrm{and}\ 6.5}$, resistivity. Thermopower and single-particle tunneling studies on some zinc-doped yttrium barium copper oxide superconductors. Enhancement of thermopower in the high Tc superconductor yttrium barium copper oxide ($YBa_2Cu_3O_7$) and related compounds [42].

Prof. Umarji Arun M, from IISC Bangalore has done the following successful research in the thermoelectric domain:

Silicides are a potential candidate for high temperature applications such as heating elements, protective coatings, ceramic engines etc. because of its non-toxicity, availability of raw materials, chemical and thermal stability. Despite its advantages, the thermoelectric performance (*ZT*) of the material is low. So, efforts are on in enhancing the thermoelectric performance of the material. Band structure engineering and phonon engineering are some of the methodologies in improving the material properties. This can be done by chemical doping and nanostructurization. This in turn can be carried out by doping the material with *Mn*, *Co*, *B*, etc. Nanostructurization can enhance *ZT* value by decreasing the thermal conductivity. Effect of Composition on thermoelectric properties of polycrystalline $CrSi_2$, chromium disilicide, *Mn* and *Al* on thermoelectric properties of chromium disilicide, control oxygen stoichiometry and thermoelectric properties in $(RE)BaCo_2O_{5+\Delta}$, mechanically alloyed chromium silicide, Nanostructuration via solid state transformation [43 – 45].

Dr. R. Gopalan from Centre for Automotive Energy Materials has done successful research in high T_c superconductors, magnetic materials, Li-ion battery, thermoelectrics, structure-property correlation of functional materials, processing of nanopowders of *Fe-Co-Sb* alloy by RF plasma technique [46 – 49].

Prof. Pallab Banerji from IIT Kharagpur has done the following successful research in the thermoelectric domain. His area of interest is low dimensional semiconductors: structures & devices, materials for energy applications, such as thermoelectricity and photovoltaics, photonics, III – V and other compound semiconductors.

Exploration of *Zn* resonance levels and thermoelectric properties in iodine doped *PbTe* with *ZnTe* nanostructures, Carrier transport phenomenon and thermoelectric properties in melt-grown tellurium doped *n*-type $Bi_{0.88}Sb_{0.12}$ alloy, thermoelectric properties of $PbSe_{0.5}Te_{0.5}$: $x\,(PbI_2)$ with endotaxial nanostructures: a promising *n*-type thermoelectric material. An alternative approach to optimal carrier concentration towards ideal thermoelectric performance. Enhancement of thermoelectric power factor through modification of electronic structure in *PbTe*: *Cr*. Dramatic enhancement of thermoelectric power factor in *PbTe*: *Cr* co-doped with iodine. Embedded *Ag*-rich nanodots in *PbTe*: enhancement of thermoelectric properties through energy filtering of the carriers. Gain structure induced thermoelectric properties in PbTe nanocomposites [50 – 53].

Prof. Aritra Banerjee from University of Calcutta has done the following successful research in the thermoelectric domain.

Synthesis and characterization (transport, magnetic and optical properties). Defect induced structural and thermoelectric properties. The effect of quenching from different temperatures. Correlation between defect and magnetism of low energy Ar^{+9} implanted and un-implanted $Zn_{0.95}Mn_{0.05}O$. Magnetic properties of *Mn*-doped *ZnO*: the role of synthesis route, *Mg* and *Al* co-doping of *ZnO* thin films: effect on ultraviolet photoconductivity, magnetic, resonance, optical properties [54].

Dr. Kaurav Netram from Govt. Holkar Science College Indore has completed the following research work in the thermoelectric domain.

He has work on thermal properties (including, thermopower) of iron based materials. Our investigation shows that these materials could be used for low temperature refrigeration. Some of the recent results on *FeSe*/*FeTe*/*FeS* compounds are under discussion. Enhancement of the thermoelectric performance by *Y* substitution in $SrSi_2$. A room-temperature *ZT* value of approximately 0.4 is thus achieved for $Sr_{0.92}Y_{0.08}Si_2$, about one order of magnitude larger than that of stoichiometric $SrSi_2$. The high value and complicated temperature dependence of thermopower (*S*) in $YMn_{1-x}Ru_xO_3$ compounds. Presently, working on the tailoring of properties in pervoskite type materials, which depends on effective and precise control of the chemical pressure by way of replacing the ionic radii of *A*/*B* atoms. This is not only because specific electronic, magnetic and thermal properties are coupled to specific valence states of the *A*/*B* atoms in these oxides, but also because even a small nonstoichiometry may frustrate the desired properties, such as valence mixing. In other cases, certain presence of nonstoichiometric defects is desirable, such as in ionic and/or electronic conductors in batteries, fuel cells, etc. In fact, this fascinating and promising research field is still widely debated, as the enhancement of thermoelectric performance and fundamental physical mechanisms are yet far from being ultimately clarified and/or achieved. This task implies to probe the changes in the various thermal transport properties, in particular, the thermoelectric performance by changing the chemical pressure in $A_2B'B''O_6$ type double perovskites materials. At present, he is at sample preparation stage.

Dr. Kumar Chattopadhyay Maulindu from Raja Ramanna centre for Advanced Technology has studied temperature dependence of thermoelectric power and thermal conductivity in ferromagnetic shape memory alloy *Ni* 50 *Mn* 34 In 16 in magnetic fields, Thermoelectric Power Studies on $YBa_{2-x}Ca_xCu_3O_{7-\delta}$ System [55].

Dr. D. Siva Prahasham from Centre for Automotive Energy Materials ARCI has done nanomaterial synthesis, characterization, consolidation, structure-properties correlation. XPS, SPS processing, thermoelectric materials and device fabrication, nanocrystalline *Fe-Co-Sb* thermoelectric alloy powder by RF plasma technique.

Dr. Raj Kishora Dash from University of Hyderabad has done research on nanomaterials (metals, metal oxides, carbon nanotubes and graphene) properties, morphology of Bi_2Te_3 nanostructured thermoelectric materials, rational synthesis of morphology controlled Bi_2Te_3 nanostructured thermoelectric materials. Applications of nanomaterials/nanotechnology in sensors, heat transfer, aerospace, NEMS, automotive, solar cell, nano fluids. MEMS, NEMS, sensors, bio-MEMS, microfluidic devices and nano/micro fabrication. Thermodynamic behavior of a model covalent material described by the environment-dependent inter-atomic potential, effect of chemical synthesis parameters on the structure.

Dr. G. Vaitheeswaran from ACRHEM,University of Hyderabad has done research on solid state theory, material science, magnetism, superconductivity, high-pressure studies, elastic and mechanical properties investigated using first principles density functional calculations (DFT). Study of structural, mechanical and high-pressure behavior of high energy materials. Double perovskites (spintronic materials), multiferroics, rare-earth compounds, rare-earth and transition metal oxides, Heusler alloys, study of materials under extreme conditions.

Dr. Manjusha Battabyal from ARCI has done research on powder metallurgy, squeeze casting, SPS and HIPping, thermoelectric materials and device fabrication, high temperature materials, transmission electron microscopy, thermophysical properties, mechanical testing.

Prof Ranjan Kumar from Punjab University has done research on theoretical condensed-matter physics: study of structure, phonons, electronic and mechanical properties, thermodynamic properties of pure and doped (*B*, *N*) graphene, effect of pressure on electronic and thermoelectric properties of magnesium silicide. First principle investigation of the electronic and thermoelectric properties of Mg_2C, effect of disorder on electronic, magnetic and optical properties of Co_2CrZ Heusler alloys. [56 – 57]

Dr. D.K. Mishra from CSIR-NPL has conducted his research on developing the materials with promising low and high temperature semiconducting thermoelectric property, exploratory synthesis and characterization of new inorganic compounds skutterudites, Mg_3Sb_2-based Zintl phase compound, half-Heusler-based bulk nanocomposite in order to improve in thermoelectric performance, high temperature materials for thermoelectric conversion (e.g. skutterudites, Mg_3Sb_2 Zintl phase compounds, Half-Heusler/Full-Heusler nanocomposites and other novel materials), simulation of crystal structures, analysis of electron diffraction pattern.

Dr. Debanand Sa from Banaras Hindu University has conducted his research on correlated electron systems, low and high temperature superconductivity, Fermi and non-Fermi liquids in low dimensional systems, Kondo and quantum impurity problems, nested and spin-Peierls systems, ferroic and multiferroic materials, emergent gauge theories, topological insulators and superconductors.

Raman scattering in orthorhombic multiferroic $RMnO_3$, superconductivity in $Na_xC_oO_{2\cdot y}H_2O$, hidden quantum critical point in a ferromagnetic superconductor, superconductivity from a non-Fermi liquid: A Ginzburg-Landau approach, a generalized Ginzburg-Landau approach to second harmonic generation.

Ms Monika Mudgel from National Physical Laboratory has studied the negative thermoelectric power of over-doped $Bi_2Sr_2CaCu_2O_8$ superconductor, anomalous thermoelectric power of $Mg_{1-x}Al_xB_2$ system with x = 0.0 to 1.0.

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