US DoE-Topic # 29D: Low-cost, conformal, and efficient thermoelectric modules for on-detector electronics cooling

U.S. DEPARTMENT OF ENERGY
Office of Science

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Acknowledgement

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Overview

- Introduction to Nanohmics
- Technology background
- High-level vision for large-area, conformal TECs
- Program objectives
- Conformal TEC applications
- Summary

CONVERSION Materials
SENSING Technologies
MEASUREMENT Instrumentation

Electro-optics
Energy conversion
Biomolecular
Transducer materials
Computational Imaging
System integration

NANOHMICS

APPLIED SCIENCE

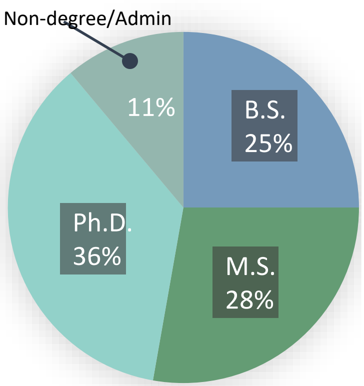
-Sensor/transducer materials
-Electromagnetic · Wavefront
-Molecular/Inks · Material interfaces
-Energy conversion · Heat/Emission
-Computational science/AI

INNOVATIVE ENGINEERING SYSTEM SOLUTIONS

-Microfabrication · Electronics
-Vacuum deposition · Coatings
-Embedded systems · Layout
-Sensors · Component integration
-Mechanical · Industrial design

-Thermal control · Electrodynamics
-Electro-optics · Electrical engineering
-Mechanical design · Control Systems
-Prototype · Low volume production
-Real-time computational imaging

Degree Distribution



Founded: Austin, TX 2002
Staff: 46 technical

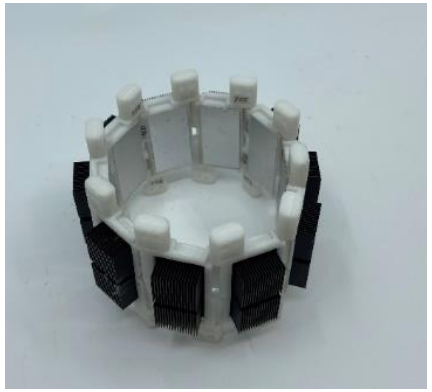
Facility: 13,500 sq.ft. industrial lab/flex
R&D: Industrial Sensors, Smart instrumentation

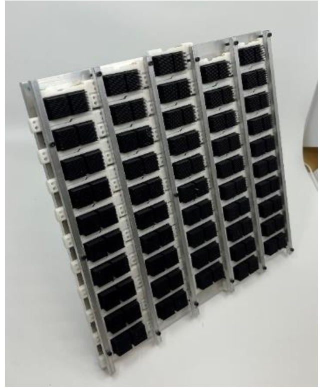
Nanohmics Company Capabilities

- Thermoelectric Devices
  - Cooling: current drives heat
  - Power Generation: temperature gradient generates current
- Capabilities
  - Materials fabrication and characterization
  - Device design and simulation
  - Thermoelectric device and systems fabrication and characterization
  - Cooling and power generation applications
- Products under development
  - Large-area and conformal TE cooling device (DoE)
  - Thermoelectrically-cooled Jacket (NAVY)
  - TEC Knee Therapy Wrap (IRAD)

Cooling Jacket application (NAVY)

DoE





TEC conformal and large-area technology

TEC wrap

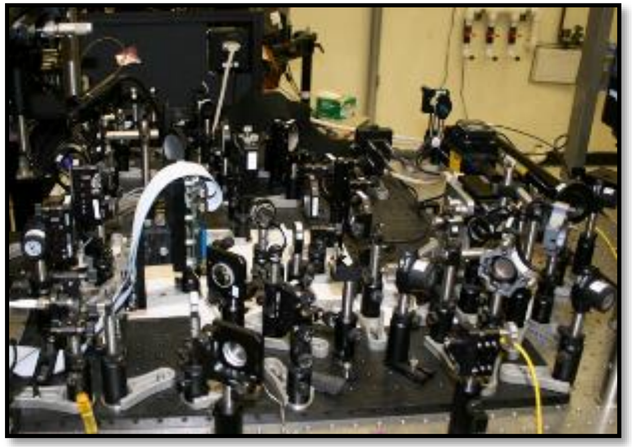
Cooling Therapy

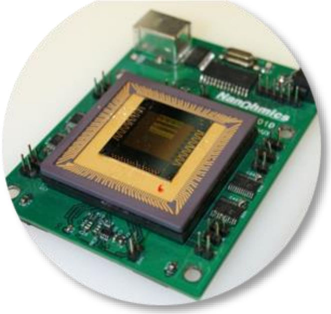
Conventional

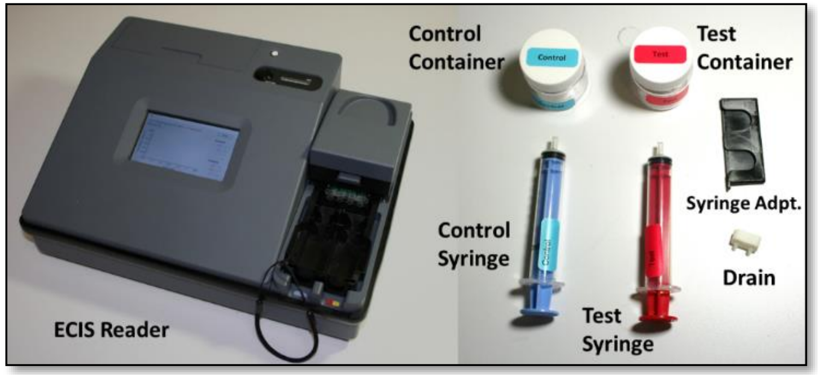
Nanohmics Company Capabilities

- Instrumentation Development

- Capabilities
  - Optical spectroscopy
  - Low-noise electronics
  - Digital signal/image processing
  - Real-time computational imaging
  - Precision measurements
  - Rapid full-custom prototyping
- Advanced products
  - Zowave^{TM} passive wavefront correction (Several in field, LRIP w/ a prime)
  - ECIS^{TM} water toxicity sensor (100+ units delivered and in use, active IDIQ)
  - GlideLine^{TM} parachute navigation system (sold entire product division)







Program Overview

- **Program:** DoE-SBIR Phase-II program, 30 months (NCE)
- **Participants:** Nanohmics (lead), University of Virginia
- **Consultant:** Capstan Technology, Jefferson Lab
- **Program goals:**

  Design and fabricate efficient, low-cost and conformal TEC systems for on-detector electronics cooling

  - Enhance COP of TEC

  - Fabricate 6” x 18” conformal TEC

  - Construct cooling system for on-detector electronics

Technical Objectives

Technical Objective 1: Design and fabrication of high-ZT thermoelectric modules - Completed

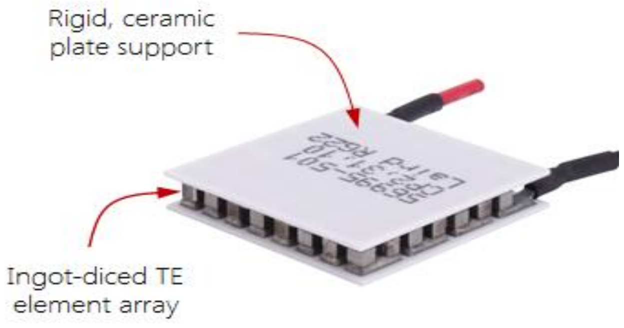
Technical Objective 2: Performance demonstration of fully-operational modular assemblies (TE alpha prototype) - Completed

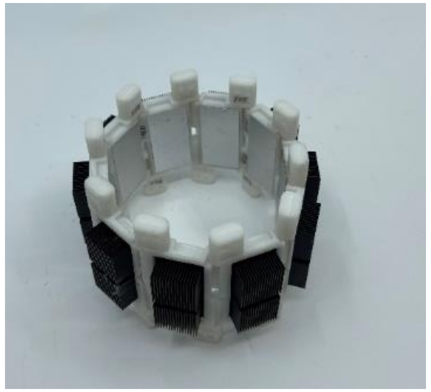
Technical Objective 3: Design of a modular TE system for on-detector electronics cooling - Completed

Technology Innovation: Modular Thermoelectric System - Thermolynx

- Modularity provides large-area, high-efficiency thermal management solutions as required for on-detector electronics cooling
- ΔT =71°C measured at $T_{ambient}$ = 25°C, higher compared to Commercial TE
- CoP >2 with cooling power > 0.75 W/cm^2 ($T_{ambient}$ = 25°C, ΔT=10°C)- Milestone achieved
- Conformable and compliant for high thermal interface contact
- Adaptable sizing and flexibility meets new application requirements
- Designed for rapid prototyping w/ integrated heat exchangers
- Low-profile is configured for wearable/textile comfort
- Low-cost manufacturing process ($199/sq.ft.)

Commercial TEC

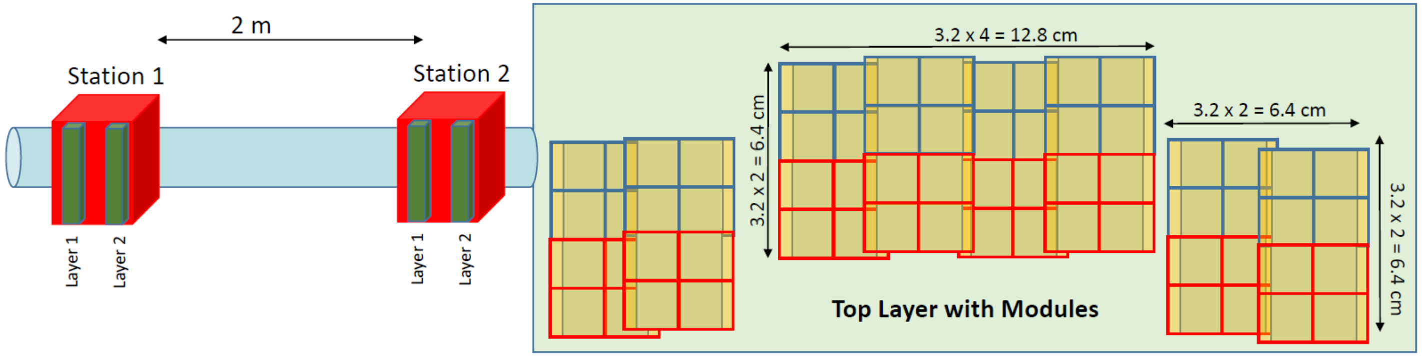


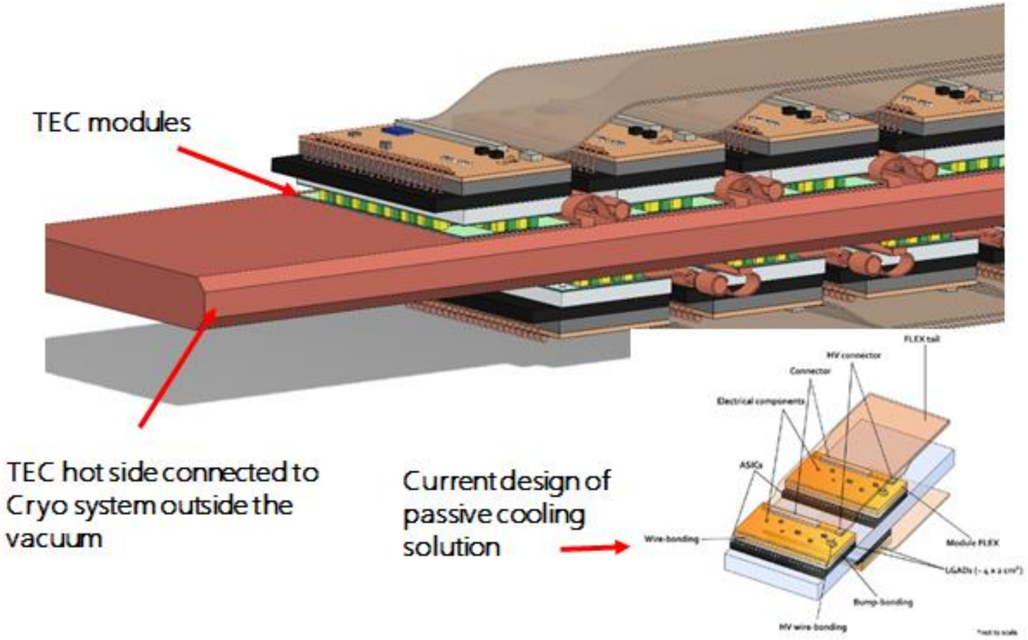


Thermolynx system

Application Overview/Design

Roman Pots modules designed by university of Kansas team (Dr. Michael Murray)

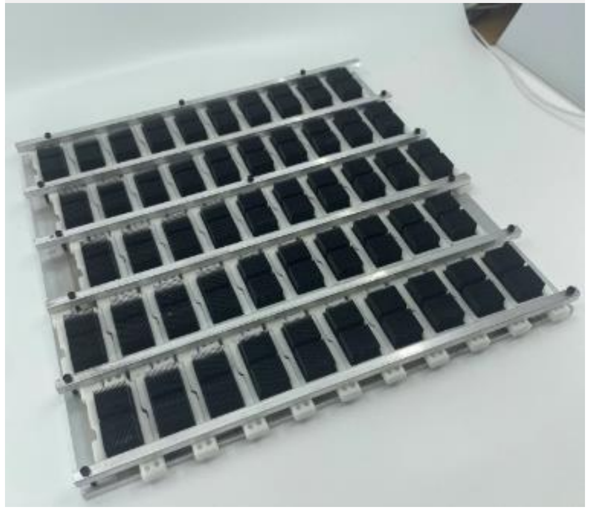




- ➢ In collaboration with Dr. Murray, Nanohmics' designed a low-profile, Conformal-Backside cooling system for Large-Area, Detector Electronics (C-BLADE) cooling system into Roman Pots of the EIC
- ➢ Looking for funding for fabrication and testing

Technology Innovation:

Nanohmics designed and fabricated conformal TEC devices to cool on-detector electronics and maintain a temperature below 20 °C during Phase II



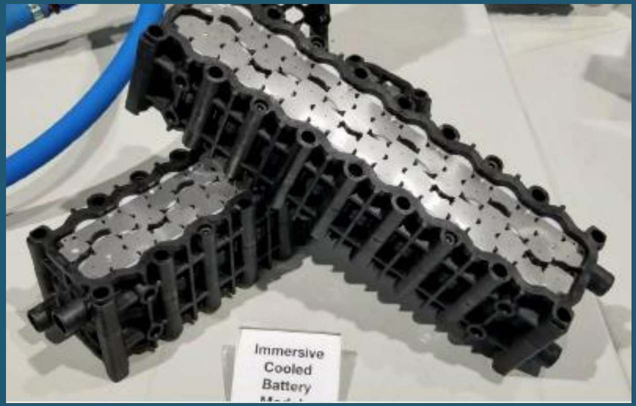
ThermoLynx-Powered Commercial Applications

Entry Products

- –Wearable **PPE (welding, first responders, soldiers, clean room)**
- –Wearable **medical (**ambulatory cold therapy, cast-integration)
- –**Cold chain/fixture thermal management**
- –**Enclosure air conditioning (wall/appliance-mounted)**
- –Portable **and battery-powered food & beverage**
- –**Scientific and biotech thermal cycling/precision thermal control**
- –**Consumer comfort cooling**

MODULAR TE PROVIDES LARGE-AREA, HIGH THERMAL INTERFACE CONTACT, PROGRAMMABLE COLD MANAGEMENT

PPE ENVIRONMENT COOLING



EV BATTERY MANAGEMENT

5G ERA COMM COOLING

THERAPEUTIC/MEDICAL WEARABLES

Phase II program work plan

Program Objective: Developed low-cost, efficient and conformal TEC fabrication with CoP>1.5 for ΔT~10°C cooling of on-detector electronics

Impact: Enable detector to maintain a temperature below 20 – 25 °C

Phase II goal: Demonstrated cooling performance of a 12" x 12" conformal TEC prototype device and cooling system suitable for large-area detector's electronics cooling

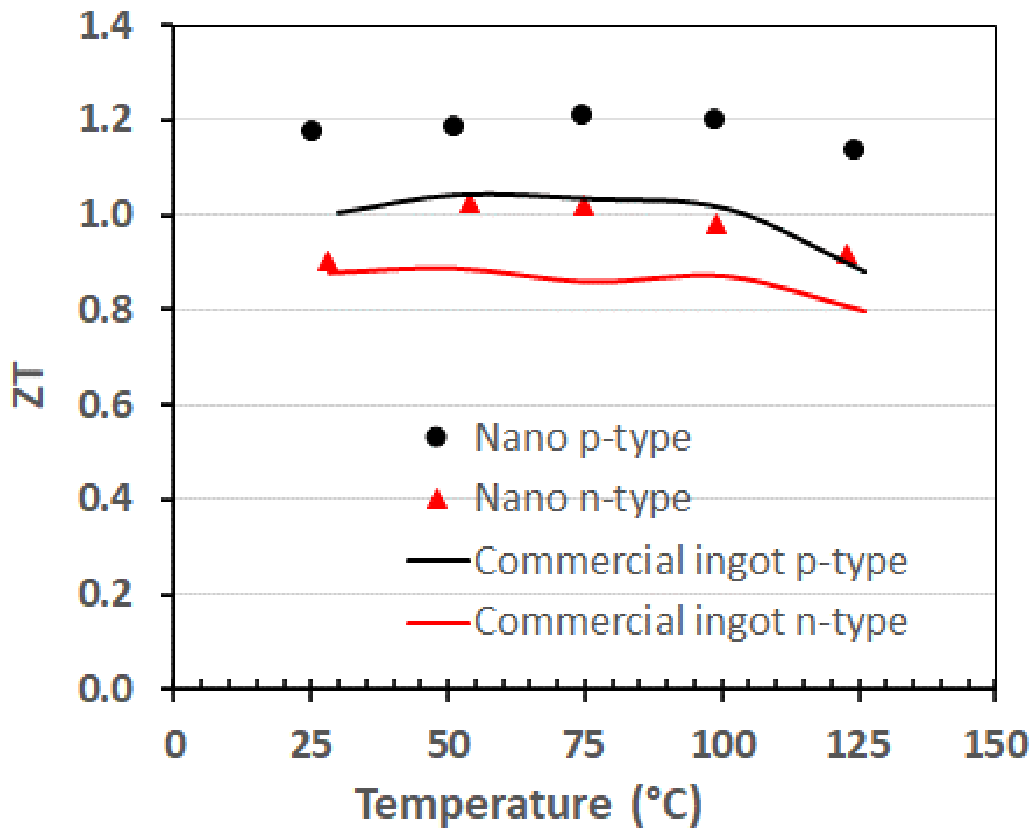
Team capabilities: Extensive TEC design, fabrication, and commercialization experience. Flexible/stretchable medical sensor technology development experience.

SBIR PHASE I PROGRAM PERIOD (MONTHS): 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30

TECHNICAL OBJECTIVE Work Plan Tasks	Milestone
1 Program kick-off with sponsor	
Establish, analyze, and document system requiremnts	Kick-off meeting; specification slides
2 Optimization of high-ZT thermoelectric materials	
Synthesize TE materilas Optimize TE composition and process	Fix TE compositions of p- and n-type with ZT around 1.0
3 TE consolidation across fiberglass and electrode development	
Consolidate TE materials across fiberglass Develop contact materials Characterize and optimize metallization layer	6" wide metallized TE element array across fiberglass with ZT around 1.0 and contact resistance < 10 μΩ-cm^2
4 Concept demonstration unit developments and optimization	
Optimize dielectric and thermal spreader materials Design and assemble TEC unit Characterize the CDU unit	Fabrication of 6" wide row module with cooling performance demonstration
5 Heat exchanger design and component fabrication	
Design and simulate hot side heat exchangers Fabricate mechanical components	Fabrication of optimized heat exchanger for TEC hot side
6 Fabrication of alpha-prototype conformal TEC System	
Design and fabricate alpha-prototype TEC Optimize materials and components Design and fabricate electrical components	Fabrication of 6" x 18" conformal TEC system
7 Alpha unit performance demonstartion	
Characterize alpha-prototype TEC Validate performance by third party	Full third party validated alpha-prototype cooling performance
8 Beta design of on-detector electronics TEC cooling system	
Design on-detector electronics TEC cooling system Optimize materilas and components	Fabrication of on-detector electronics TEC cooling system
9 Volume manufacturing process design	
Design TEC volume manufacturing components Optimize TEC roll manufacturing for low-cost production	Detail low-cost roll process TEC manufacturing plan
Phase II deliverable: Phase II final report, fully characterized 6" x 18" conformal TEC system, manufacturing design documentation	

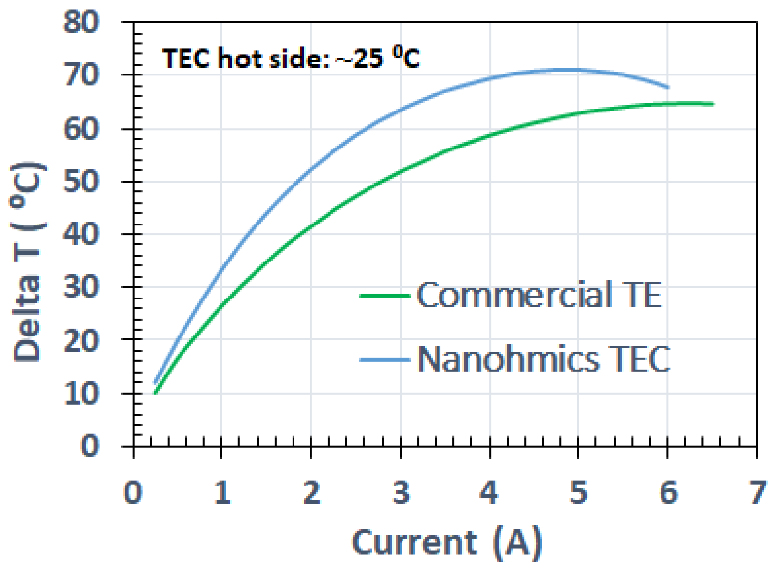
High-performance thermoelectric materials

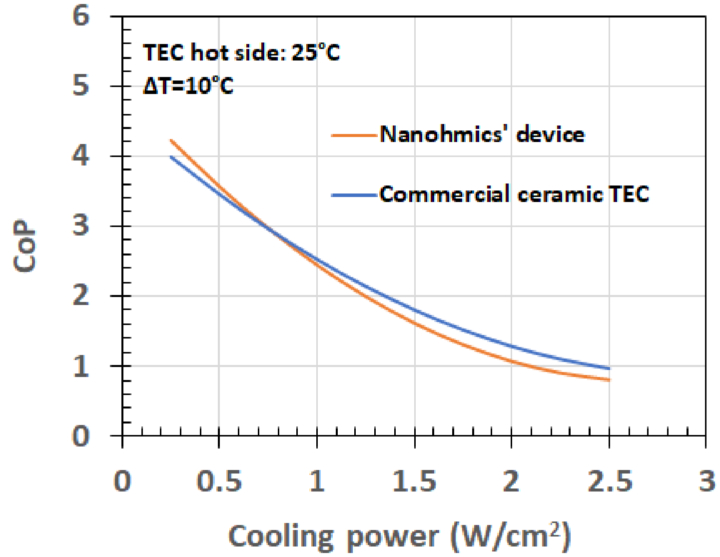
- High performed TE materials synthesis
- Base compositions: $Bi_{0.5}Sb_{1.5}Te_3$ (p-type), $Bi_2Te_{2.7}Se_{0.3}$ (n-type)
- Room temperature figure of merit (ZT): 1.2 (p-type), 0.9 (n-type)
- Better TE materials compared to commercial TE
- CoP proportional to ZT
- Targeted CoP ~ 2.0 with ΔT = 10 °C



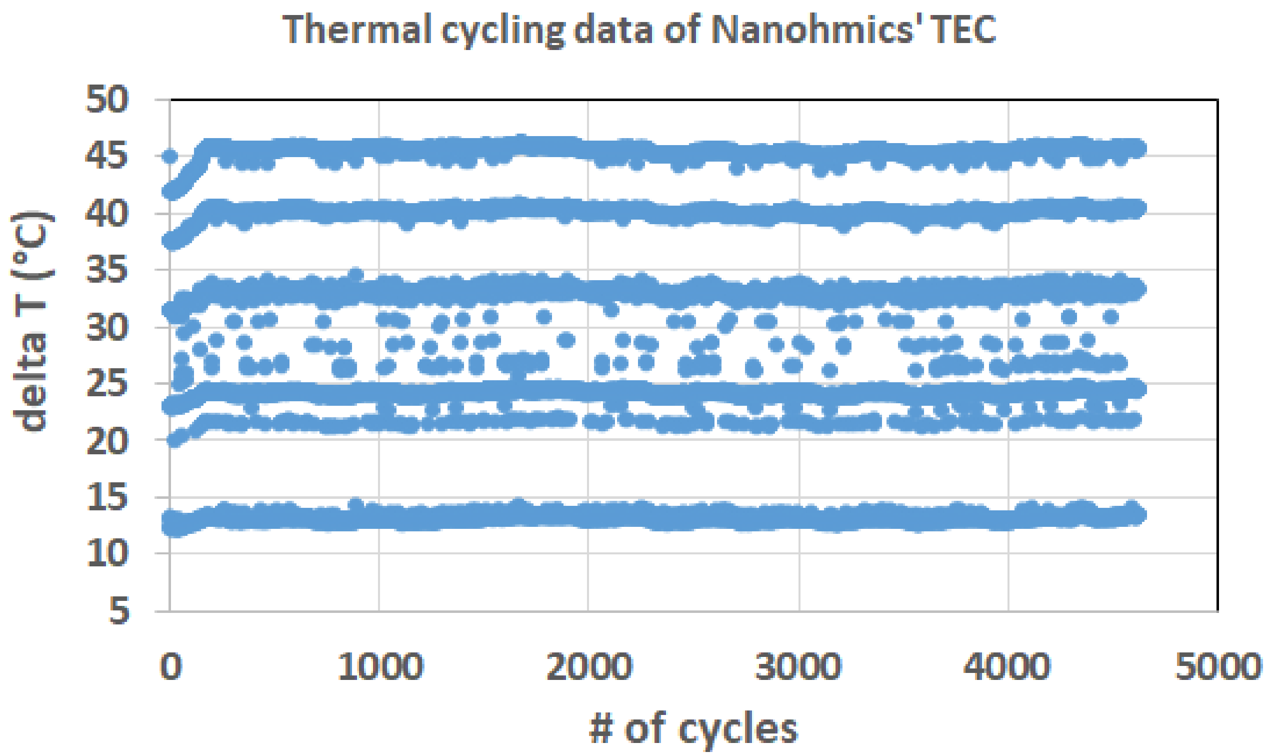
Cooling performance of *Thermolynx* modules

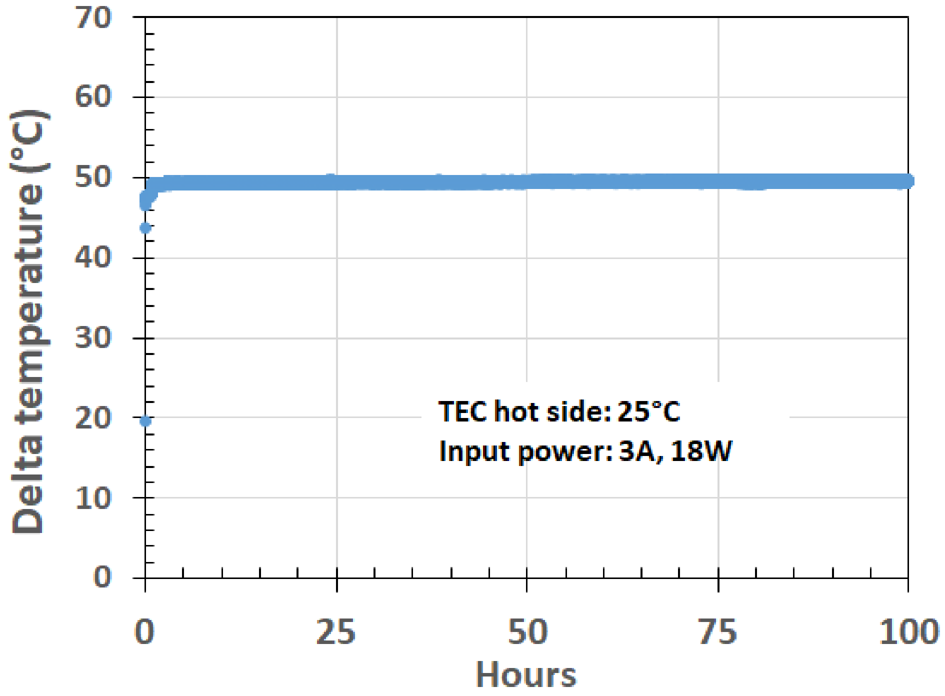
- 20mm x 41mm TEC
- CoP and cooling performance measured at $\Delta T = 10°C$ and $T_{hot} = 25°C$
- $\Delta T = 71°C$ measured at $T_{ambient} = 25°C$, higher compared to Commercial TE
- CoP >2 with cooling power > 0.75 W/cm^2
- Competitive performance as high quality commercial TEC
- Targeted cooling performance for room temp cooling applications such as on-detector electronics cooling





Thermal stability data





- Thermolynx modules show robust mechanical and thermal stability for 5000 cycles and 100 hours of continuous operation

Short-term commercial Plans

- **5000 Thermolynx modules delivered Q4 2023**
- Freeze core, power and tail module industrial design, hard-tooling initiated **Q3 2023**
- **Wearables cooling product (jacket/cover-all) designed and fabricated Q4 2023**
- Finalize industrial design with transition partners, fabrication completed **Q4 2023**
- **Jacket comfort/ergonomics human subjects IRB study complete Q1 2024**
- Full assembly sampling articles **Q4 2023**
- **Connector progressive die tooling investment Q4 2023**
- Launch welder's jacket/other PPE products **Q1 2024**
- **Human subjects IRB study for post-surgical knee therapy device Q3 2023**
- **Establish therapeutic product partnership by Q2 2024, 510k filing (class II predicate device) regulatory approval path for 5S Li+, 20V**
- **Scale for consumer/enclosure/industrial markets Q2 2024**

-500 working samples fabricated and tested

-funding committed to hard tooling the core Thermolynx module, shroud and terminal units for 8-module wearable assemblies

Summary

- Nanohmics has developed low-cost, conformal, and efficient thermoelectric cooling modules (Thermolynx devices)
- Thermolynx devices are based on PCB substrates, and assembled using automatic and tape & reel-based manufacturing processes
- The Thermolynx devices are modular in structure, and amenable to a large-area cooling system using stretchable and mechanically-complaint electrical connectors
- A CoP ~ 2.0 and cooling power > 0.75 W/cm^2 measured for room temperature cooling applications (T_{hot} ~ 25 °C, ΔT= 10 °C) such as on-detector electronics cooling
- Thermolynx are robust, thermally-stable, and easily integrable into cooling systems
- Collaborated with University of Kansas to design Roman Pot cooling system
- Nanohmics' devices are ready to build the detector cooling system as well as any other cooling applications, any collaboration is welcome!

Thank You!…….Questions??