Advanced Thin Film Thermoelectric Systems for Efficient Air-Conditioners

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3rd Thermoelectrics Applications Workshop

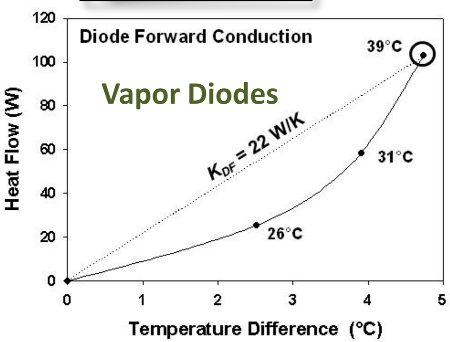
March 21, 2012

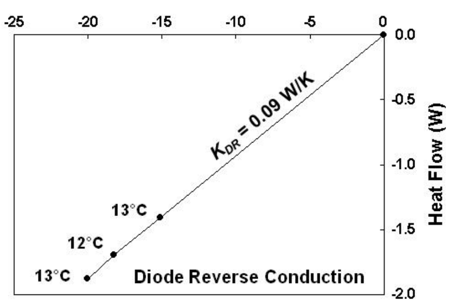
Introduction

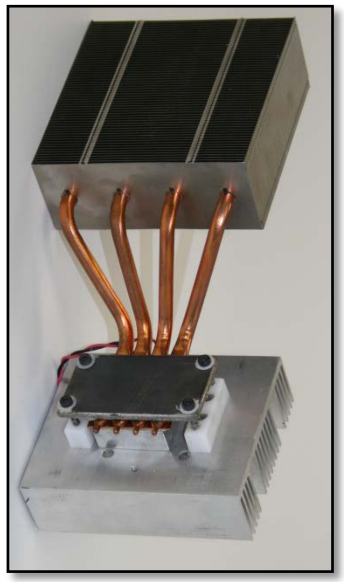
- Sheetak - Background
- ARPA-E (Advanced Research Projects Agency • ENERGY) funded Projects
  - NEAT : a seedling project to develop high-efficiency thin film thermoelectric coolers
  - TREATS: a low cost thermal storage system with advanced thermoelectrics for climate control in electric vehicles (Collaboration with DELPHI)

Sheetak - Background

SHEETAK COOLING ENGINES







Heat circuits result in 3× reduction in energy consumption

SMALL APPLIANCES

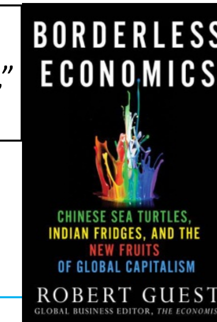
SOLD GLOBALLY

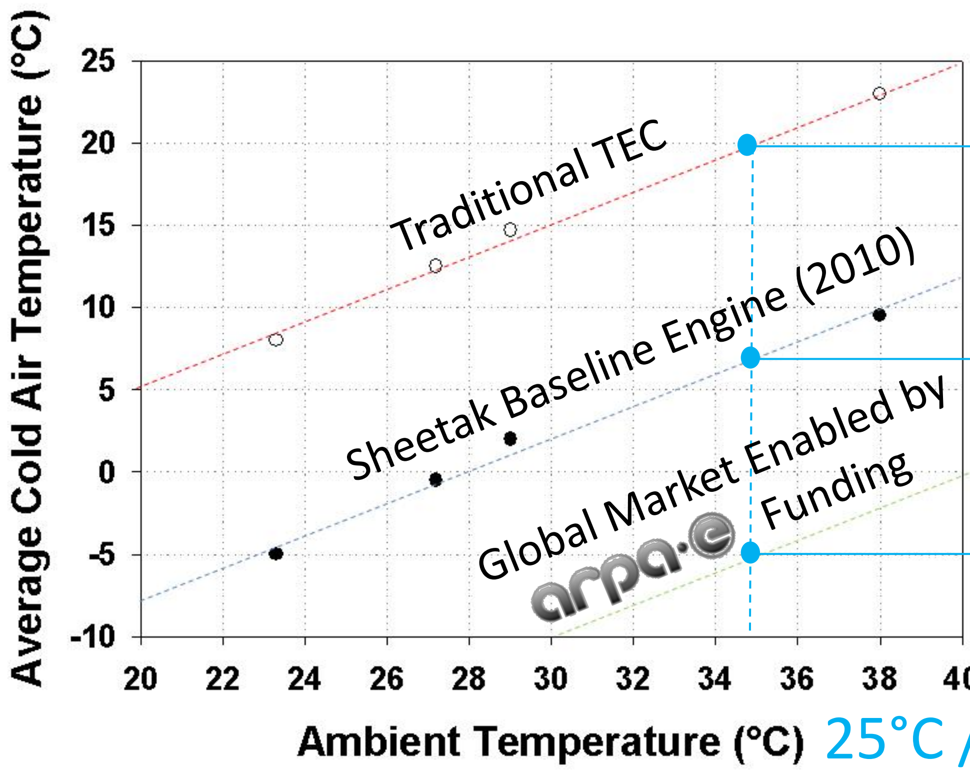
Refrigerator for the Bottom Billions

Harvard Business Review — "New Business Models in Emerging Markets," Jan-Feb 2011

THE WALL STREET JOURNAL. WSJ.com — "Indian Firms Shift Focus to the Poor," Oct 21, 2009

The Economist — "Weaving the World Together," Nov 19, 2011





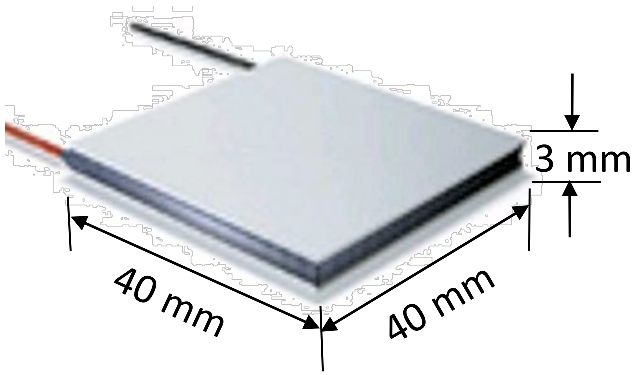
25°C / 45°F cooler temperature!

DESIGNED & ENGINEERED IN THE USA

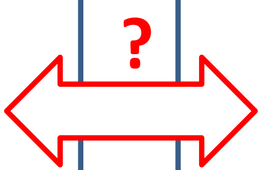
Sheetak technology has enabled world's lowest cost refrigerators

Extreme Options

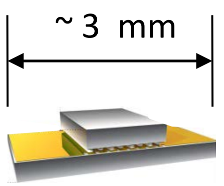
Traditional TECs



- Poor efficiency (< 10% of Carnot COP)
- High $/W of cooling power ($3.00 for 12 W cooling at COP =0.2, Qmax = 60W) limits applications
- Limited by cost of tellurium



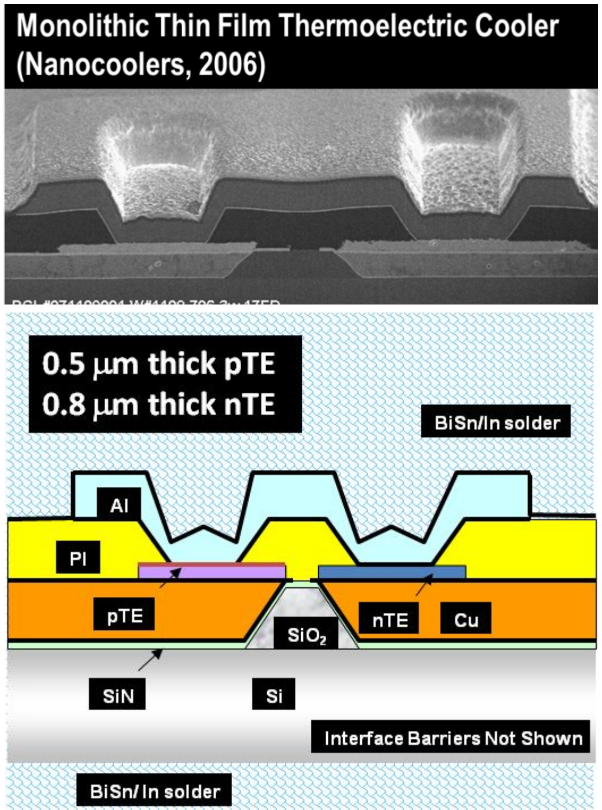
Advanced Thin Film TECs

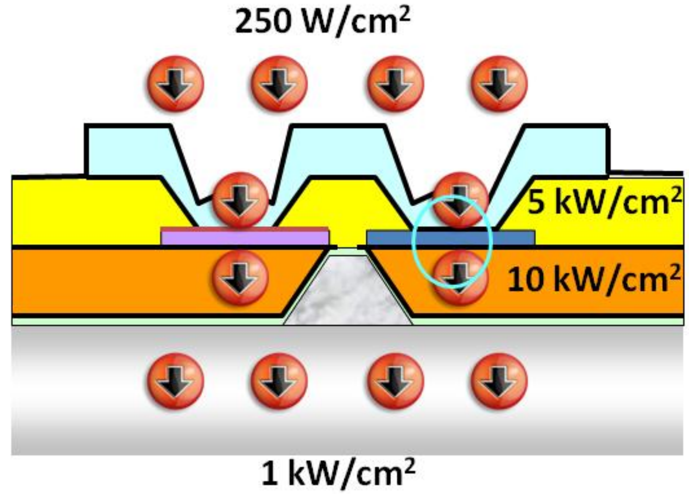


- Poor efficiency (~7% of Carnot COP) limited by heat flux (> 50 W/cm^2) and interface losses
- Low tellurium use
- Increased cost of packaging
- Limited volumes, prohibitive costs

Poor efficiency and cost metrics limit the use of TECs in practical applications

Heat Flux in Thin Film TECs





Nanocoolers, 2006

$$J_{q\max_{HOT}} = \frac{\sigma S^2 T^2}{t} \propto \frac{1}{t}$$

High heat flux exacerbates interface and substrate ΔT drops

NEAT Seedling Project

Phase I: HiE TECs

Goal: Double (2×) the efficiency of traditional TECs by providing better thermal management and eliminating temperature losses at interfaces

Jan 2011-March 2012

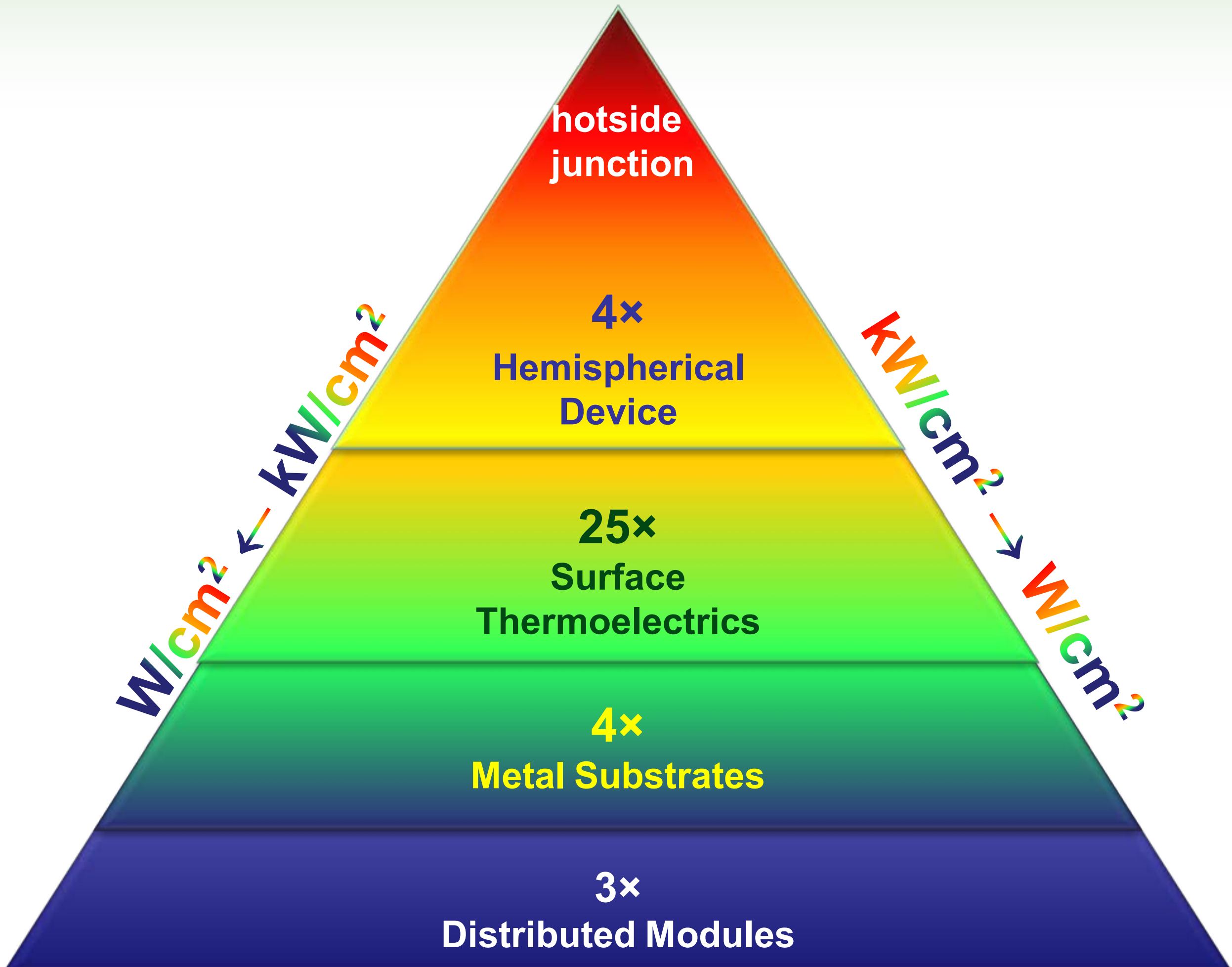
Phase II: NEAT

Goal: Double (2×) the efficiency of HiE TECs by exploiting non-equilibrium transport of electron-phonon system, and phonon-blocking layers

March- Dec 2012

NEAT technology will provide efficient, non-polluting, light-weight, low-cost cooling engines for refrigerators and ACs

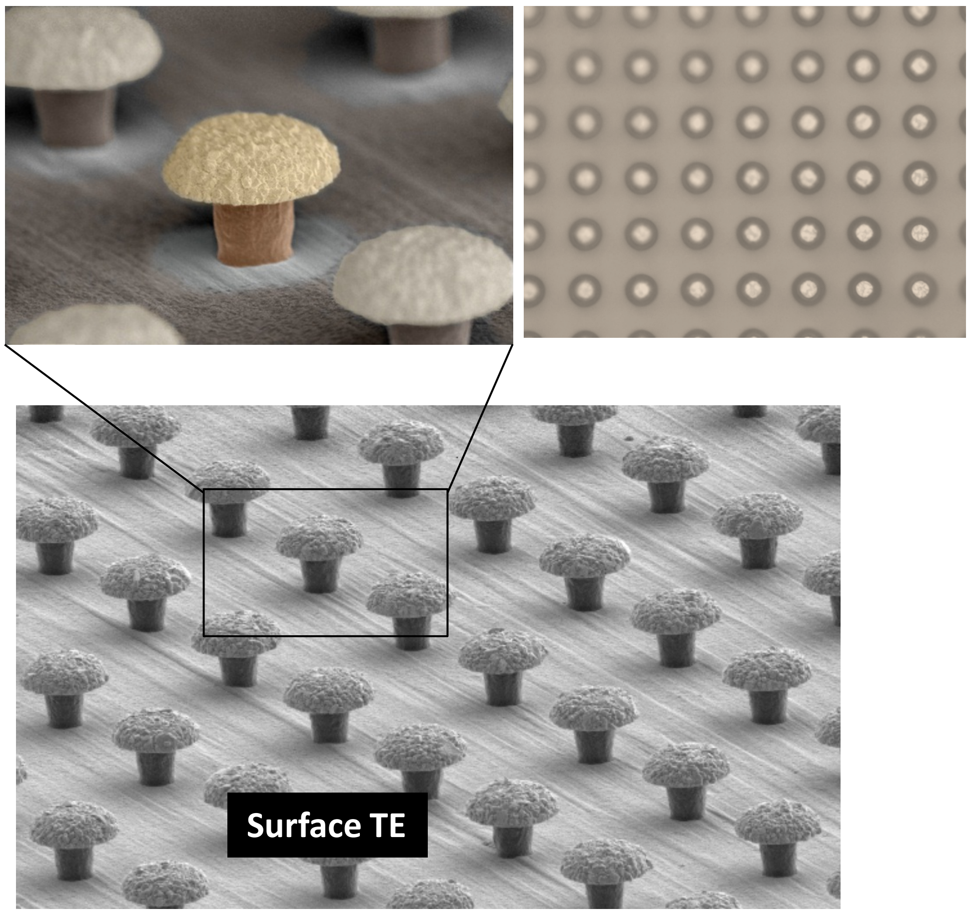
Hierarchical Thermal Spreading

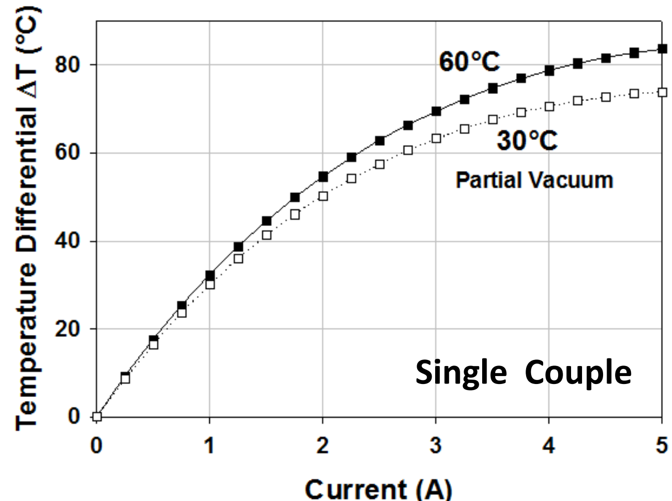


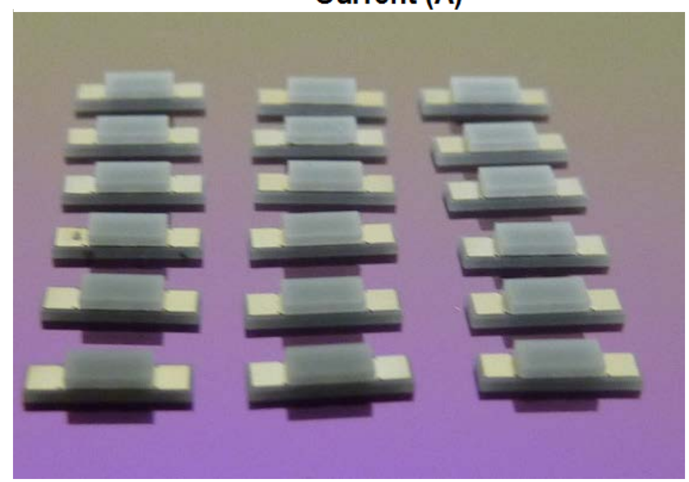
1000-fold reduction in heat flux density with minimal ΔT losses

Phase I: Early HiE Devices

Constricted Contacts







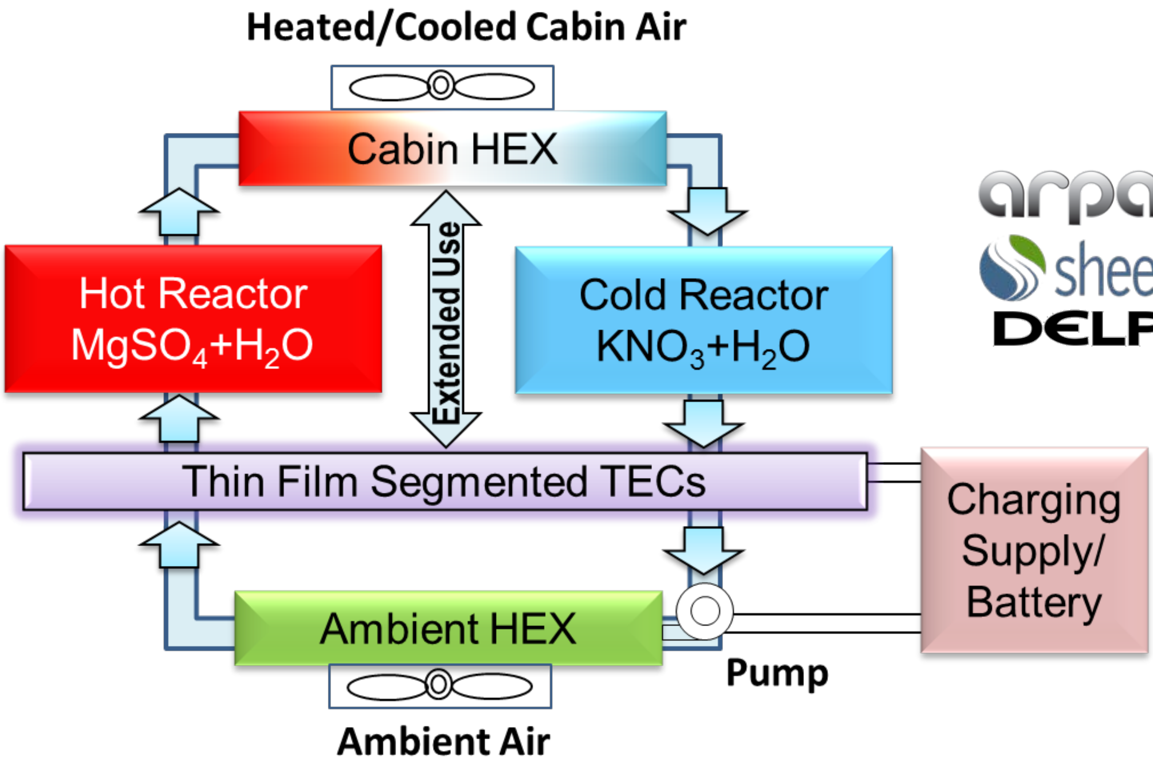
Best thin film thermoelectric cooler performances

NEAT Project Status

- **Phase I: HiE devices**
  - **Focus on packaging techniques**
  - **Rigorous performance evaluations in progress**
- **Phase II: NEAT devices (Dec 2012)**
  - **HiE TE layers interspersed with atomically-thin phonon-blocking layers, electron tunneling layers at intervals less than the electron-phonon thermalization length**
  - **Nonequilibrium effects decouple electron and phonon systems, and PB layers selectively attenuate the phonon transport**
  - $ZT \to S^2 / L_0 \sim 3$

TREATS System Introduction

- Low cost chemical storage for heating and cooling
- Advanced thermoelectric heat pumps for managing storage discharge, extended usage, and recycling of heat of vaporization
- Advanced heat exchangers, fans and pumped coolant system

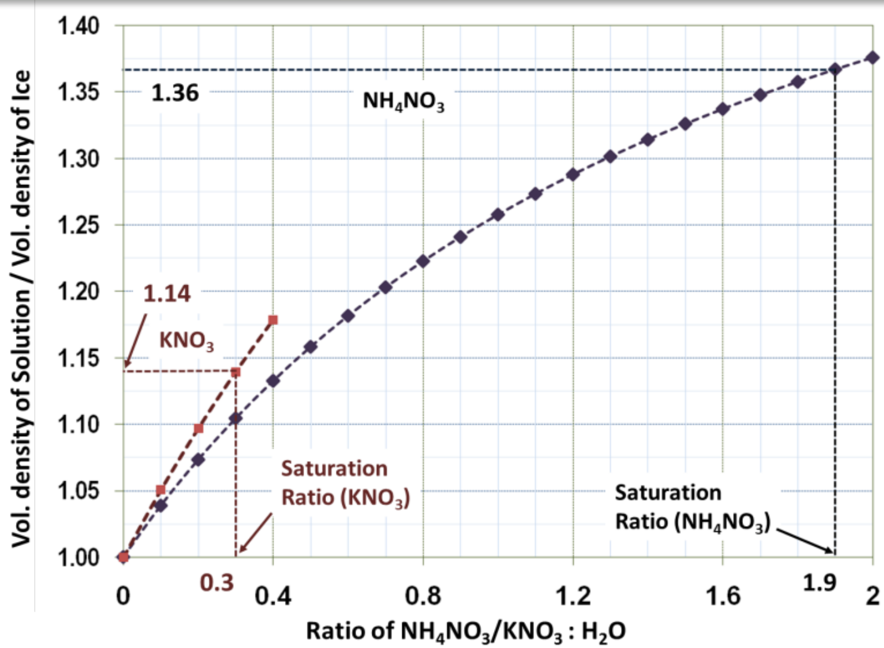


Cold Reactor Storage Media

- **Endothermic solubility of salts in water and bootstrapping by freezing point depression**
  - **Inexpensive, nontoxic material with long term stability**
  - **Increases volumetric storage of ice by 30%**

$KNO_3(s) \rightarrow K^+(aq) + NO_3^-(aq)$; $\Delta H = 345\ kJ/kg$

$NH_4NO_3(s) \rightarrow NH_4^+(aq) + NO_3^-(aq)$; $\Delta H = 312\ kJ/kg$



TREATS Thin Film Heat Pumps

- **TREATS incorporates thin film TE heat pumps with best of class materials and hierarchical thermal management**
- **Sheetak will enhance the NEAT™ coolers to include:**
  - **New materials for higher temperature operation (< 400°C)**
  - **Segmented and graded films for efficient (ZT > 2) performance over wide temperature range**
  - **Thermoelectric modules coupled to microchannel counter-flow heat exchangers**

TREATS Plan

2012

- System architecture definition
- Hot Reactor & Cold Reactor material selection
- **Demonstrate high temperature TE heat pumps**

2013

- **Demo functional Hot Reactor**
- Counterflow HX for use with TE
- Fabrication and characterization of fluidic loop

2014

- Demo functional cold reactor
- **Complete system integration and demonstration**
- Commercialization of component technologies

Sheetak Technologies

- Best in class NEAT heat pumps for -50 to 400°C applications
- Lowest cost and scalable thin film process
- Focus on novel systems
- Aggressive plans to improve energy efficiency for cooling, heating, and possibly power generation at high temperatures

Acknowledgments

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