RDECOM

Review of Interests and Activities in Thermoelectrics

DoE Thermoelectrics Applications Workshop: Jan 3-6, 2011

TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.

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OUTLINE

- Army Rationale
- Thermoelectric Power Generation
  - Soldier power
  - UAV power
- Materials Research
  - Bulk
- Thermoelectric Cooling
  - DARPA/MTO: ACM
  - NEA device idea
  - Where would these help?
- Summary

RDECOM

RATIONALE

ARL

- 3×10^5 barrels per Day!
- JP-8:
  - Base cost $3/Gallon
  - "Fully burdened cost" $42/Gallon
  - Human cost 1 US casualty per 24 trips

RATIONALE

- 3×10^5 barrels per Day!
- JP-8:
  - Base cost $3/Gallon
  - "Fully burdened cost" $42/Gallon
  - **Human cost 1 US casualty per 24 trips**

Batteries require **more supply trips**!

POINT: Power-Generation opportunities that ARL is looking at:

1. reduce batteries (soldier power)
2. reduce demand (UAV)

OEF – AFGHANISTAN (72 Hour Mission)

AN/PVS 14 (Night Vision)
(2) AA
.106 lbs/.04 watts*

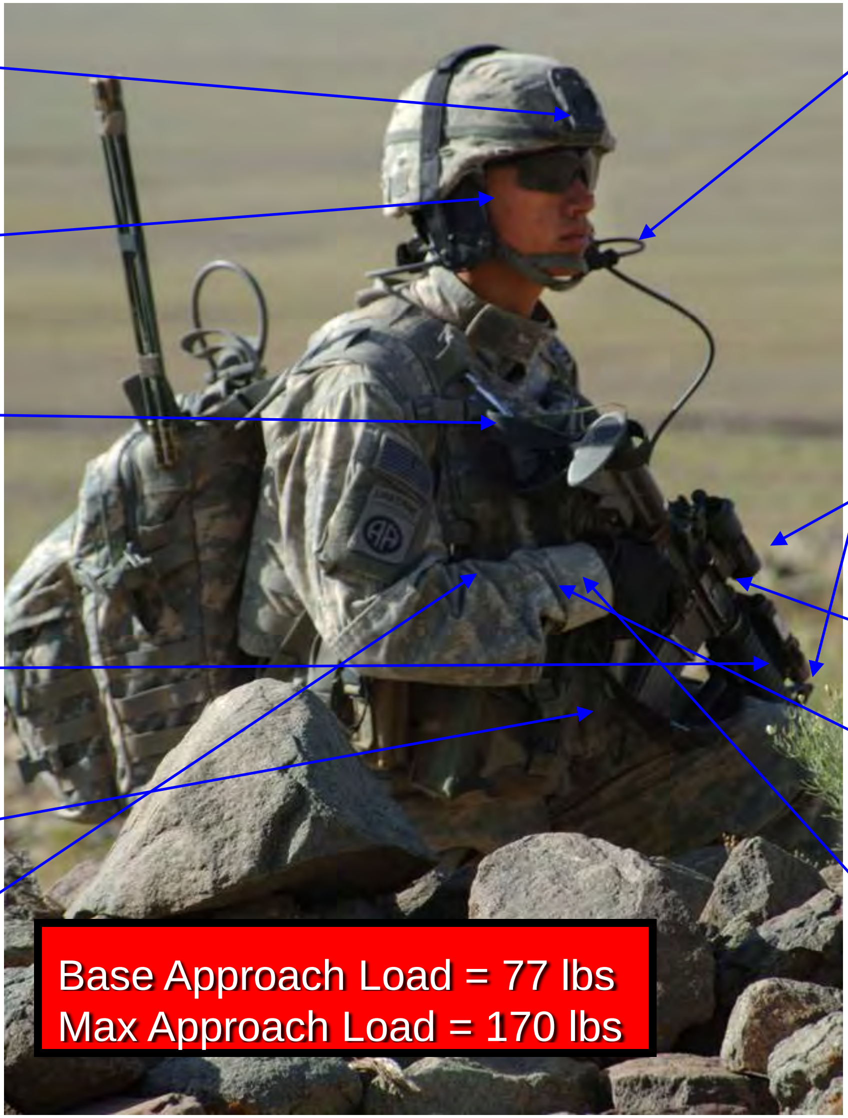
Mark VII
(1) 3.9 V lithium
.256 lbs/.167 watts*

MBITR
(8) BB 521
6.4 lbs/5.33 watts*

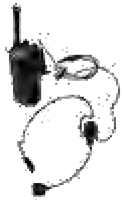
Sure Fire Light
(6) CR-123A
.222 lbs/.219 watts*

Mag Lite
(2) AA
.106 lbs/.019 watts*

DAGR
(24) AA & (1) ½ AA
1.3 lbs/.729 watts*



Head Set
(2) AA
.106 lbs/.019 watts*



PEQ-2A
(2) AA
.106 lbs/.011 Watts*

HTWS (Night)
(12) AA Lithium
.384 lbs/.68 watts*

M68 CCO (Day)
(1) DL 1/3N
.007 lbs/.00006 watts*

LMR
(8) 3600 mAh NIMH
6.4 lbs/1.51 watts*

P-Beacon
(1) 9V
.1 lbs/.049 watts*

Total: 7 types of batteries, 70 batteries, 16 lbs; 9.17 watts

1. Direct Power Generation

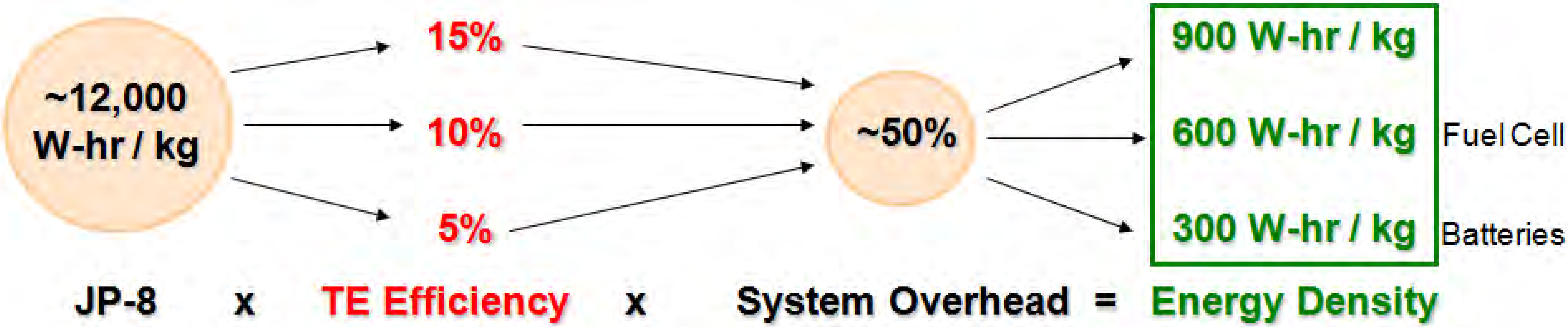
CREDIT: Brian Morgan/Ivan Lee

Goal:

- Develop small light weight power sources for the Warfighter that maximize specific energy for Soldier systems and sensors.
- High efficiency thermoelectrics could compete with fuel cells, while likely using logistic fuels

Research Areas:

- Burner development
- TE materials
- TE packaging / interconnects
- Thermal management
- Balance of plant (pumps, valves, etc)



2. UAV: “*SHADOW*”

Total weight (14.2 kg)
Main payload is imaging pod (intel)
UEL AR 741 Wankel (air-cooled)
-28 kW power, 50 kW max **(* 1:1)**
28 Volt/900-1500 W_e generator (3.5 kg)

Say…only 1/3 goes to heat…

@28 kW, then 10 kW heat		@50 kW, then 16 kW heat	
-5% TE	then 500 W_e	-5% TE	then 800 W_e
-10% TE	then 1000 W_e	-10% TE	then 1600 W_e
-15% TE	then 1500 W_e	-15% TE	then 2400 W_e

Opportunity? weight, cost, reliability, performace

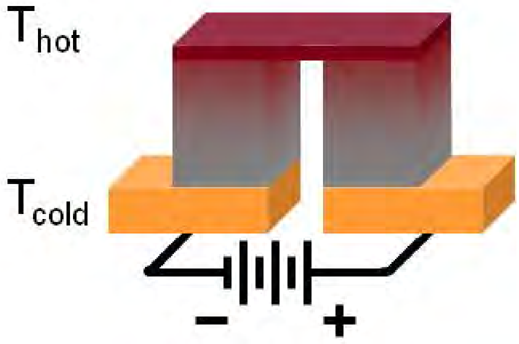
BULK

Materials Research

Basic theory:

- **Efficiency** $\propto$ **f(1/κ)**

…..as κ↓…efficiency↑



Credit: N.B. Singh/Team at Northrop Grumman

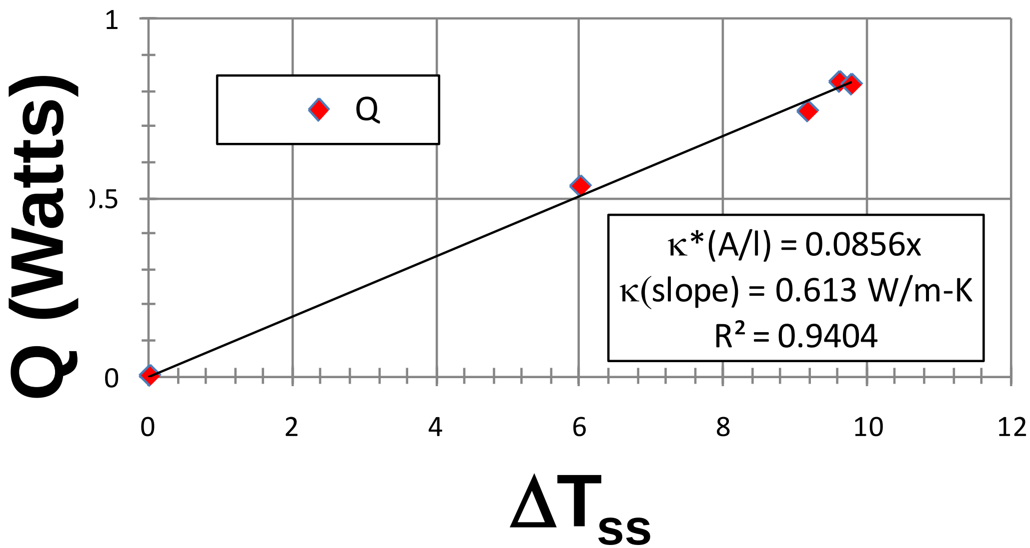
Low κ bulk (450º C)

- **$(Tl,Bi)Te_2$ ~ PbTe**

"Pseudo-PbTe"

J. Jensen, R. Burke, D. Ernst, R. Allgaier, Phys. Rev. B, Vol. 6(2), p. 319 (1972).

$$Q_\kappa = \kappa\left(\frac{A}{\ell}\right)(\Delta T_{ss})$$



- **Room-Temp.** κ ~ 0.6 W/m-K….3X better than PbTe

TE Cooling

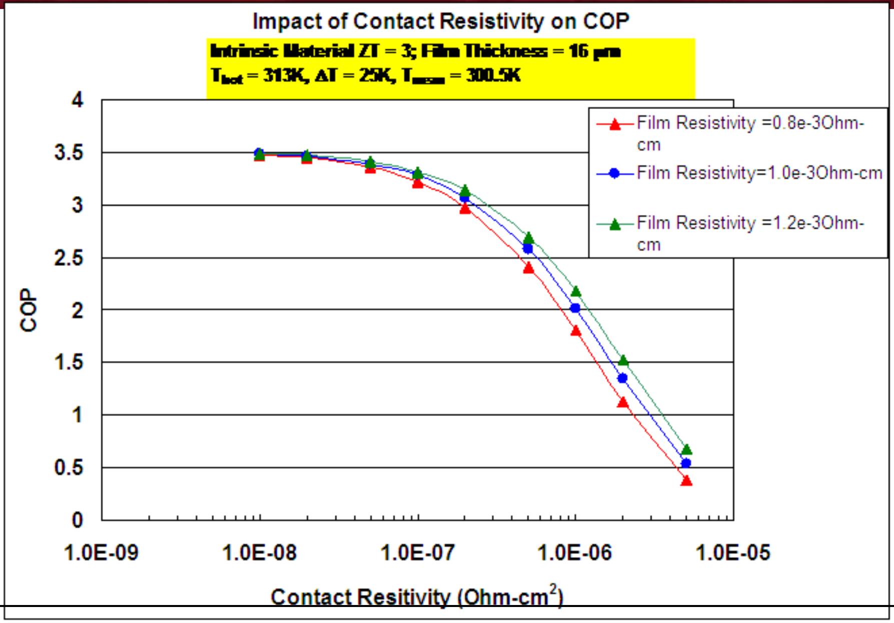
Active Cooling Modules

DARPA/MTO: ACM

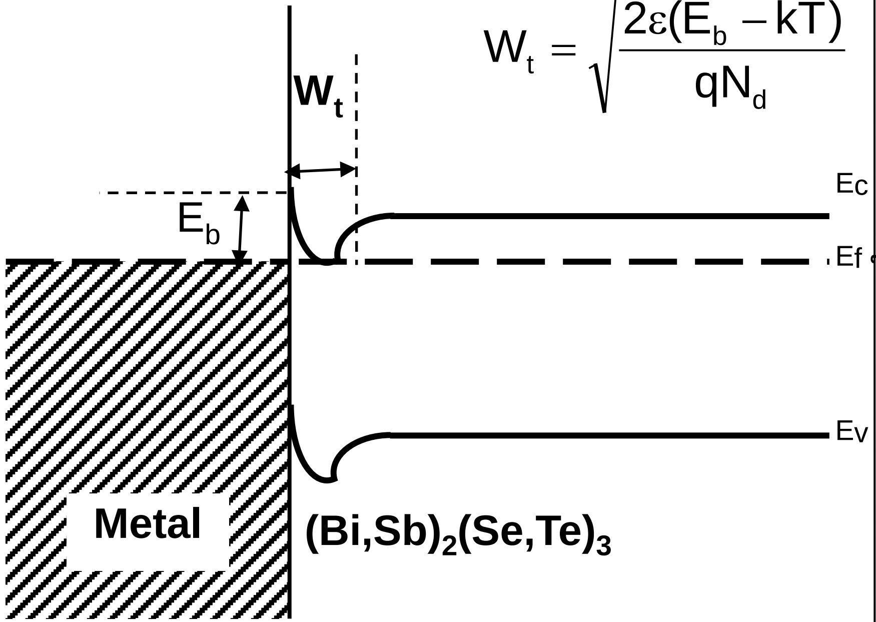
(Kenny → Bar-Cohen

PROG: *Develop high-COP devices*

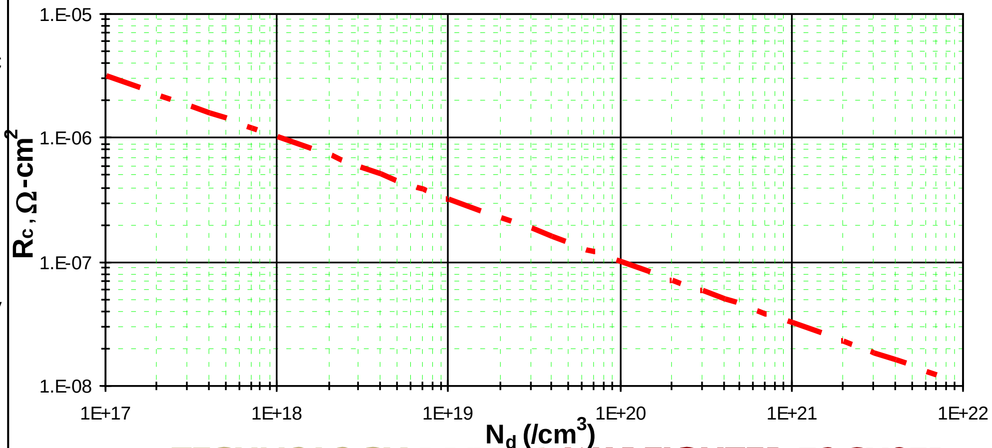
ARL: *Revolutionary Improvement in Contact Resistivity*



$$W_t = \sqrt{\frac{2\varepsilon(E_b - kT)}{qN_d}}$$

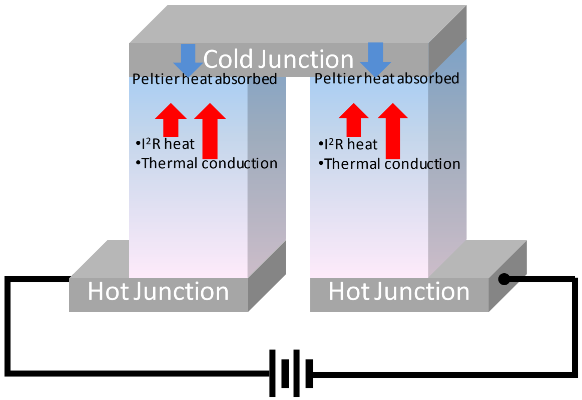


$$W_t \propto R_c \propto \frac{1}{\sqrt{N_d}}$$



Thermoelectric Cooling

Thermodynamics:



$$Q_c = -(\alpha_n+\alpha_p)TI + (\kappa_n + \kappa_p)\Delta T(A/l) + \tfrac{1}{2}I^2(\rho_n + \rho_p)(l/A)$$

$$\Delta T_{max} = \tfrac{1}{2} ZT^2 \qquad Z = \alpha^2/\rho\kappa$$

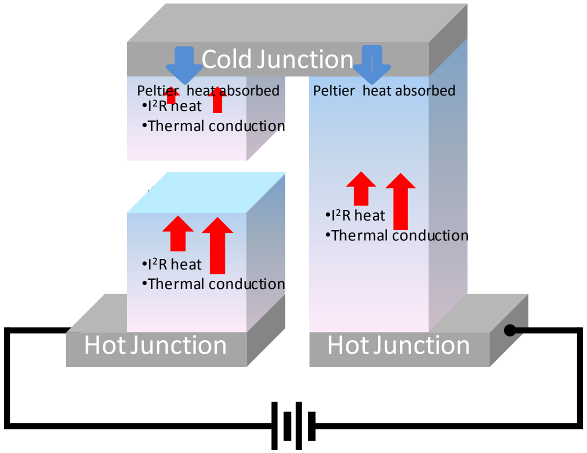
Anything else that can be done?

Thermoelectric Cooling

"What if…. "

- we incorporate a gap

1. Heat cannot be conducted
2. Current cannot flow



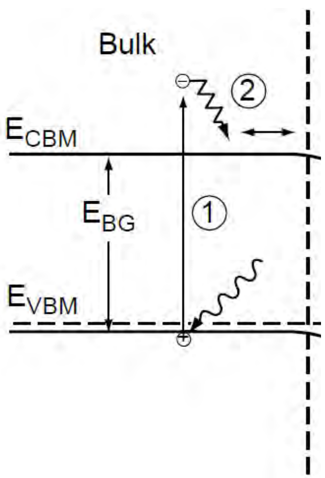
Is there something that we can do to induce the electrical current to cross?

NEA

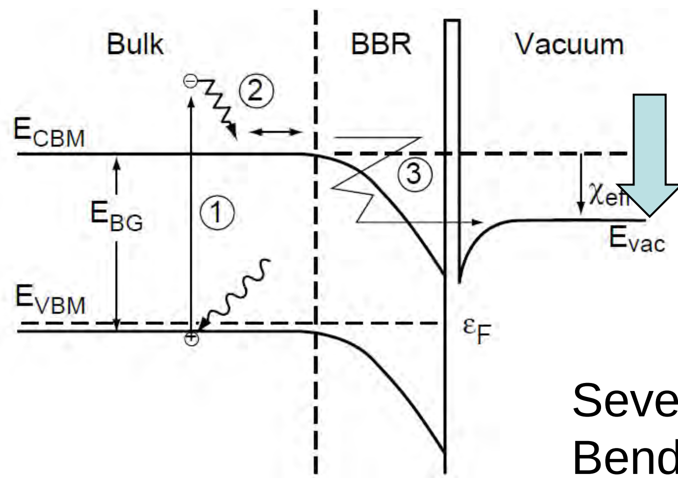
“Negative Electron Affinity”

- **Phenomenon in p-GaAs**
- **Surface treatment → severe band-bending**
- **e^- source at Stanford Linear Accelerator (SLAC)**

<u>Key:</u> Cs metal on GaAs



Surface States,
Some Band
Bending

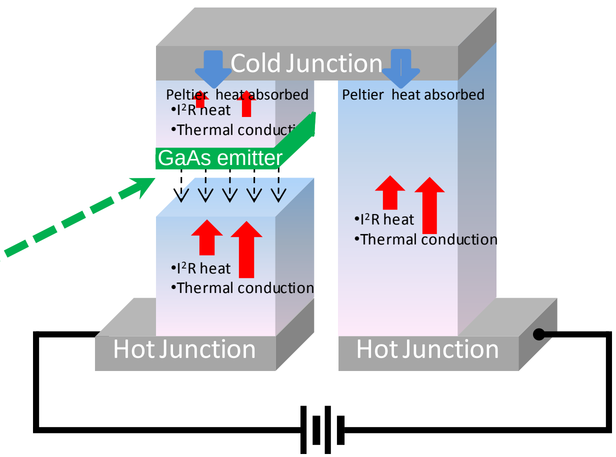


Severe Band
Bending

NEA

“Negative Electron Affinity”

- How would this work?
- Incorporate GaAs e^- emitter within gap



GaAs e^- emitter

- **Physics:**

Child’s Law: current density across gap:

$J = K\, V_d^{3/2} / d^2$

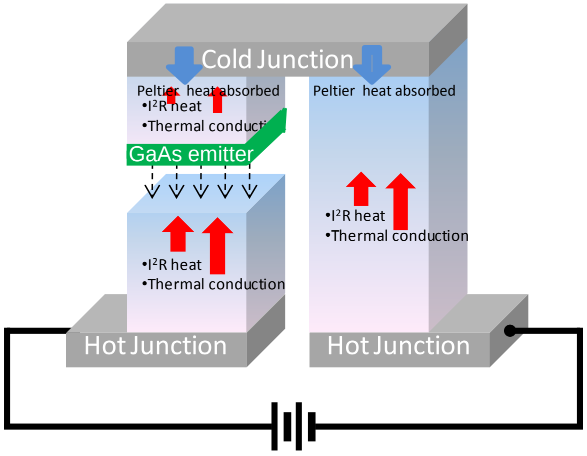
where
J = current density
d = gap spacing
V_d = Potential across d
K is a constant = $(4/9)\ \varepsilon_0\ (-2q/m)^{1/2}$

10 V ~ “d” in mm range

NEA

“Negative Electron Affinity”

- **Role for thin-film TE in practical devices**
- **Maybe:**
  - **$(Bi,Sb)_2(Se,Te)_3$/GaAs NEA Cooler**
  - **PbTe/GaAs NEA Power**



At this stage:

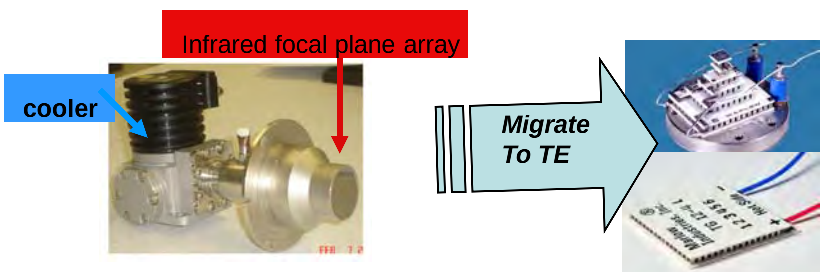
Form Analysis

Risk is OK

Thermoelectric Cooling

Unmanned Assets (UAV/UGV):

- High-performance IR would be nice
- High-performance IR needs coolers
- SADA is…



Attribute	TE 6-stage	SADA (Stir.)
Volume	7 cm^3	986 cm^3
Weight	100 g	2500 g
Cost	$800	$10,000
ΔT_{max}	133 K	235 K
Input Power	22.7 Watts	20 W (60 W_{max})
Heat Load	0.58 Watts	1.5 Watts
MTTF	unlimited	~ 10,000 Hrs.

Funding:

DARPA

ACM MTO DARPA MICROSYSTEMS TECHNOLOGY OFFICE

MDA:

Army I^2WD: Passive infrared threat warning

Collaboration:

RTI
Brimrose
Northrop-Grumman

Summary

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