Assessment of Nanofluids for HEV Cooling Applications

Jules Routbort
Energy Systems Division
May 11, 2011

Coworkers: Wen Yu, David France, Dileep Singh, and Elena Timofeeva

Project ID
pm042

Vehicle Technologies – Annual Review – May 11, 2011

Sponsored by ***Propulsion Systems Materials***

Overview

Timeline

- New project

Budget

- FY11 – $50K*

•Continuing resolution (expect total $150K)

Barriers

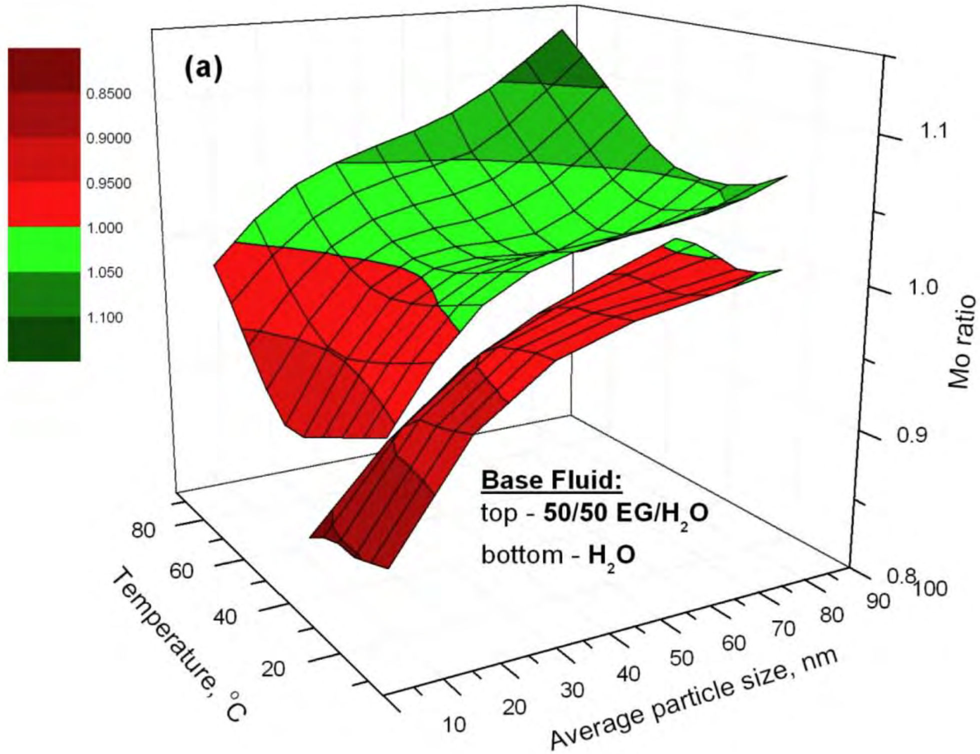
- Potential applications of nanofluids for thermal management in power electronics for HEV not established?

⇒ development of effective, affordable nanofluid
⇒ industrial acceptance
⇒ manufacturability
⇒ needs demonstration

This project complements the overall effort in the area of nanofluids for thermal management with emphasis on cooling for power electronics

Relevance

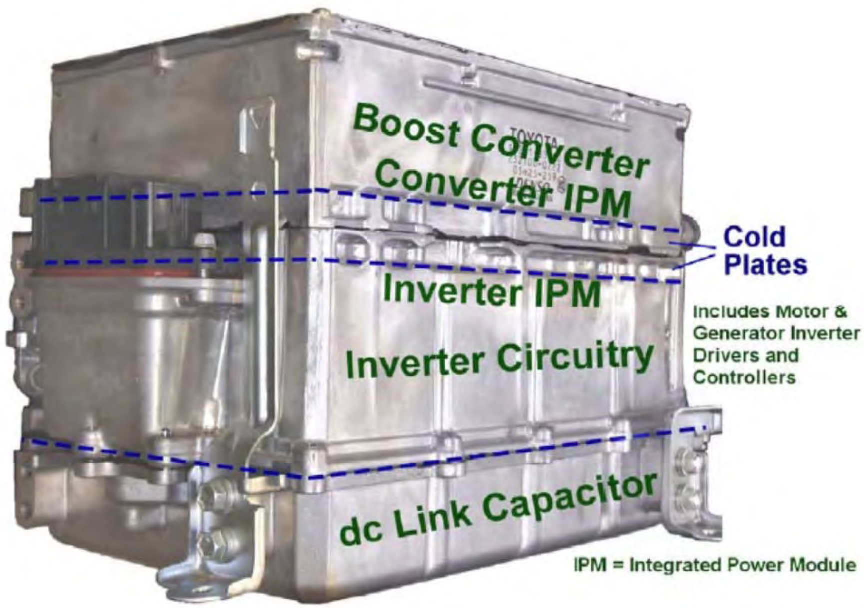
- Fluids containing nanoparticles have a <u>proven</u> ability to increase thermal conductivity and heat transfer and hence reduce the size, weight and number of heat exchangers for cooling power electronics.



Effectiveness of heat transfer for 4 vol.% SiC in EG/H_2O and H_2O

Objectives (FY11)

- Determine if nanofluids can be used to improve cooling of HEV power electronics while eliminating the low temperature coolant system.
- Assess the feasibility of engineering nanofluids to cool HEV electronics using only the high temperature coolant system.
- Develop a research program for engineering candidate nanofluids for HEV applications.



Milestones/Future Work

- Determine by calculation if an optimized nanofluid can eliminate the low temperature cooling system and increase heat transfer for cooling power electronics for HEV applications – FY11

Following depends on continued funding

- Develop and characterize the properties of an optimized nanofluid
- Establish collaborations with industry
- Demonstration of nanofluid in calibrated heat exchanger

Approach

- Specifications of the heat exchanger*
  - Heat flux = 100 W/cm^2
  - Power semiconductor junction temperature – 150°C
  - Convective heat flow to coolant (50-50 EG/water) – 105°C, only the high temperature cooling system is needed in this case
  - Laminar flow

- Estimate properties of nanofluid to meet or exceed cooling requirements
  - Develop 1–D mathematical model of cooling

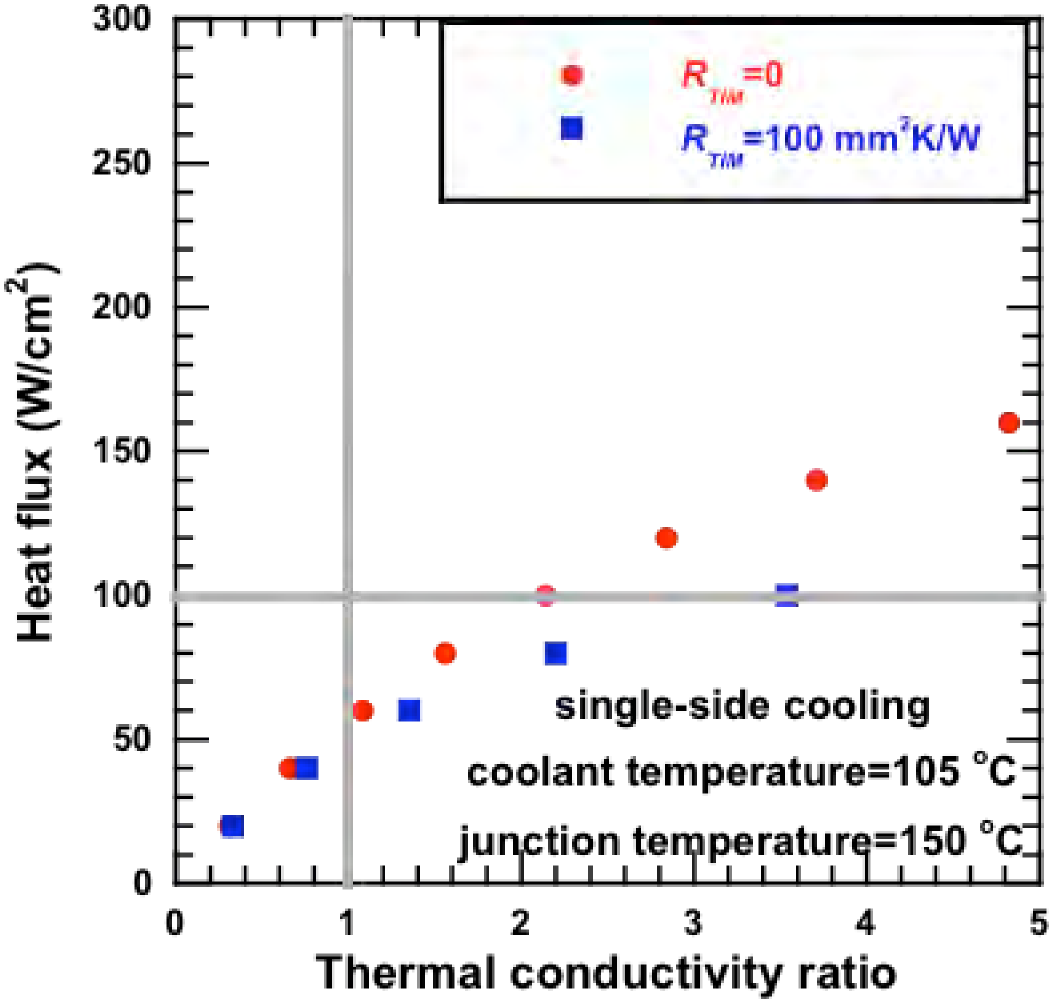
- Calculations performed with or w/o Thermal Interface Material (TIM)
  - Calculate junction temperature for base and nanofluid for single or double sided cooling

*M. O'Keefe and K. Bennion, A Comparison of Hybrid Electric Vehicle Power Electronics Cooling Options, 2007 IEEE Vehicle Power and Propulsion Systems Conference, Arlington, Texas, September 9-12, 2007.
K. Bennion and K. Kelly, Rapid Modeling of Power Electronics Thermal Management Technologies, 2009 IEEE Vehicle Power and Propulsion Systems Conference, Dearborn, Michigan, September 7-11, 2009.

Results – Heat Flux – Single Sided Cooling

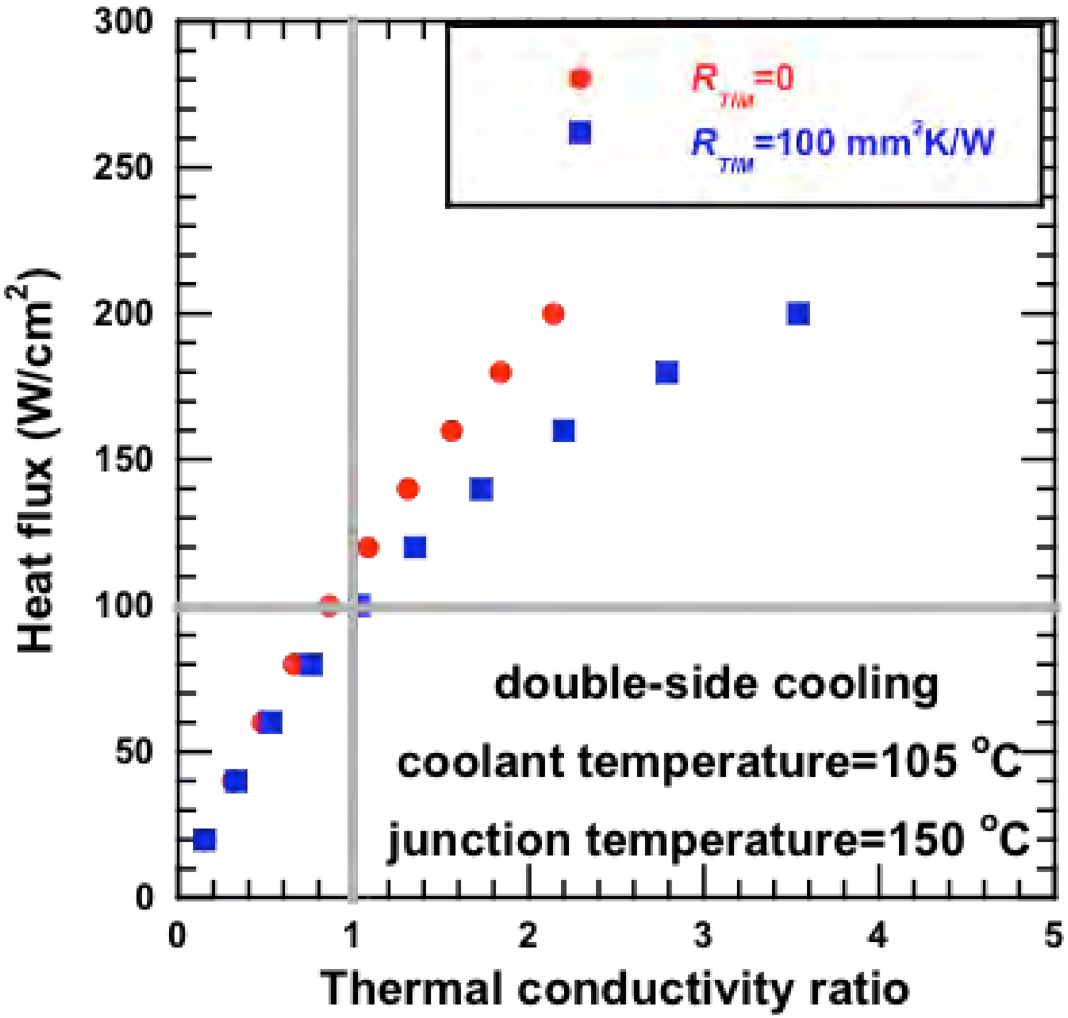
Nanofluid thermal conductivity (TC) ratio of 2 without TIM is sufficient to eliminate the low temperature coolant system.

The required nanofluid is possible with some development.



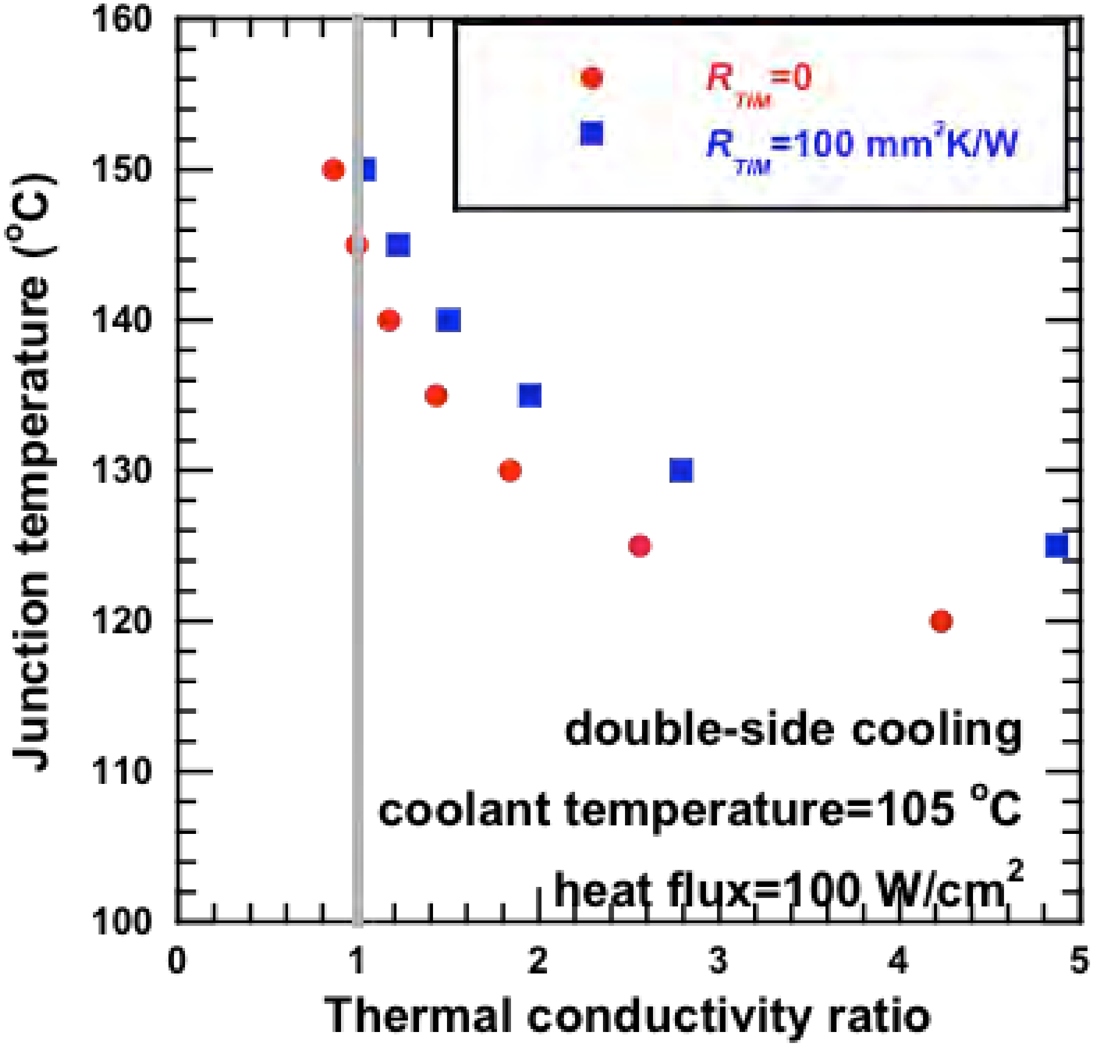
Results – Heat Flux Double-Sided Cooling

A nanofluid TC ratio of 1.5 increases heat load by ≈ 50% with TIM and by ≈ 70% without TIM.

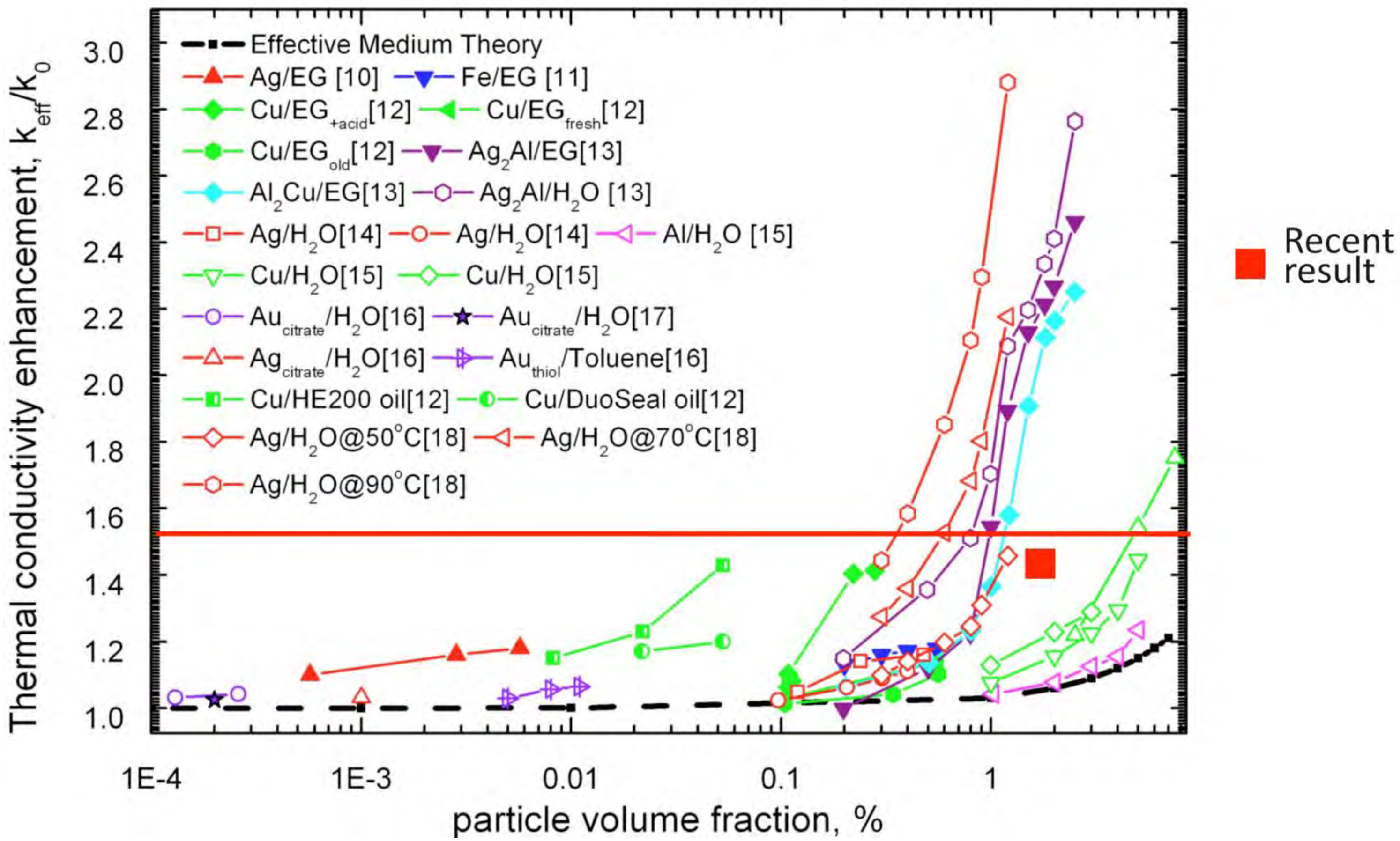


Results – Junction Temperature – Double-Sided Cooling

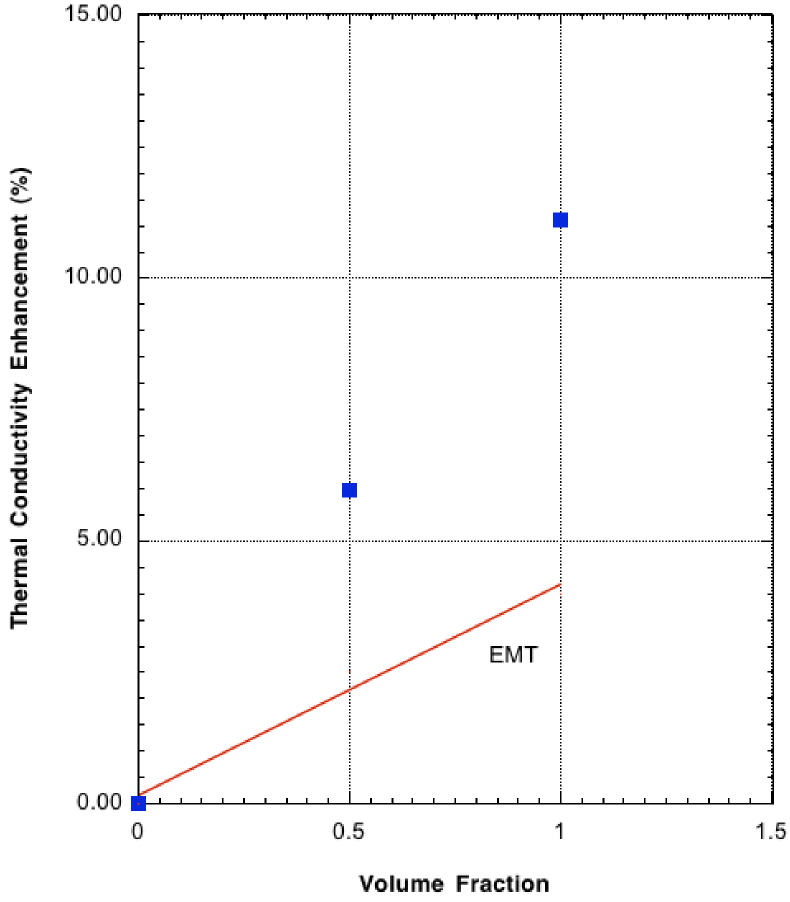
Nanofluid thermal conductivity ratio of 1.5 decreases semi-conductor junction temperature to ≈ 139°C with TIM and to ≈ 135°C without TIM

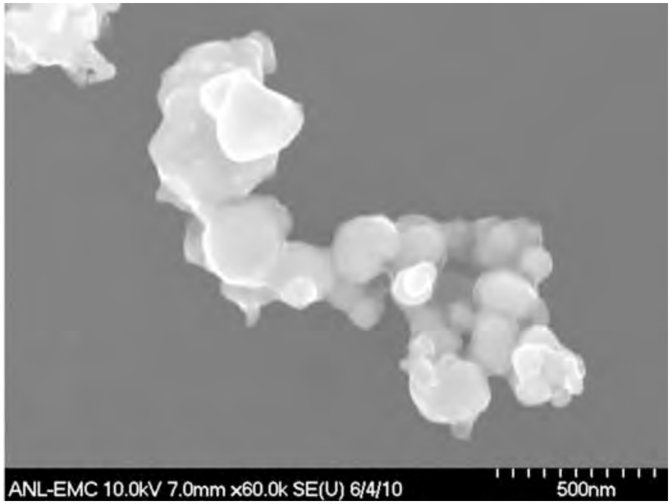


Are such nanofluids ($k_{eff}/k_o \approx 1.5$) possible? – very likely using metallic or intermetallic nanoparticles



Recent ANL work in organic fluid (for Solar Program)





Phase pure copper nanoparticles synthesized using an in situ chemical process (*D. Singh, et al., unpublished data*).

Conclusion based on analysis

- ***Calculations indicate that the DOE goal of eliminating the low temperature coolant system for cooling power electronics can be achieved if the ratio of heat transfer coefficients (equal to the ratio of thermal conductivities in laminar flow) of the nanofluid to the base fluid is about 2 without the TIM in single-sided cooling.***
- ***In double-sided cooling, the low temperature coolant system can be eliminated and the current standards of 100 W/cm^2 heat flux and/or 150^{o}C junction temperature can be improved substantially with a thermal conductivity ratio of about 1.5 with or without the TIM.***
- ***A review of the literature and ANL data indicate that the requirements for a nanofluid can be achieved using inexpensive and non-toxic metal nanoparticles.***

Path Forward (obviously depends on continued funding

- Develop nanofluid with required thermal conductivity ratios
  - Modify in-situ processing using EG/water as fluid
  - Size
  - Concentration
  - Surface chemistry control
  - Measure thermal conductivity

- Test in a heat exchanger