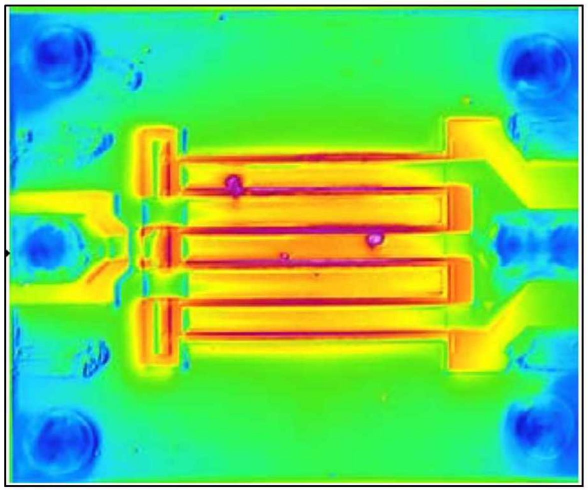
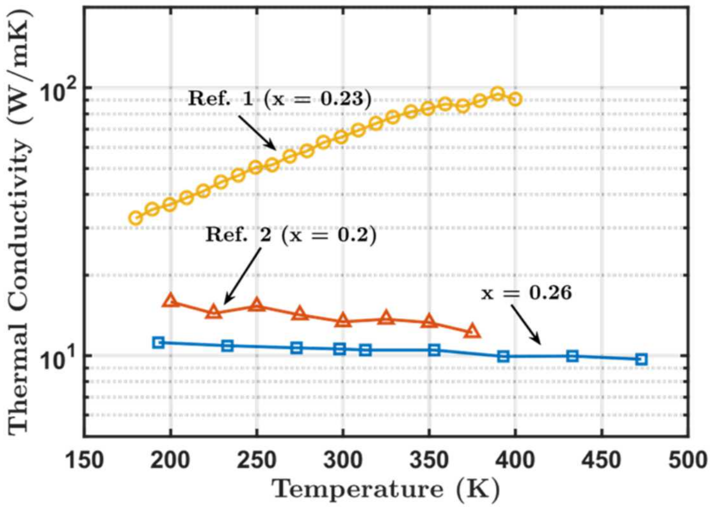
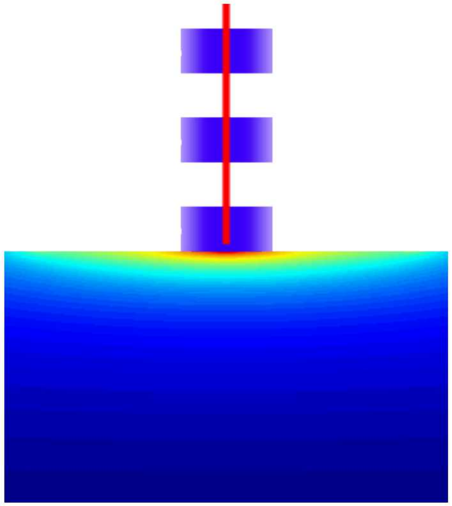
SAND2019-14029C







Thermal Conductivity of AlGaN

Assessing Alloying & Layer Thickness

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Team: Thomas Beechem
Andrew Allerman

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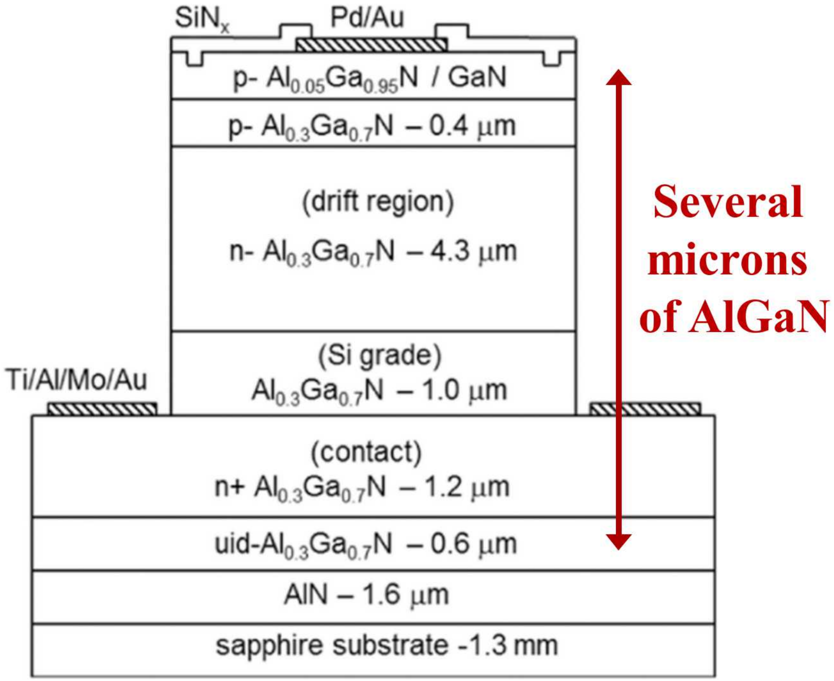
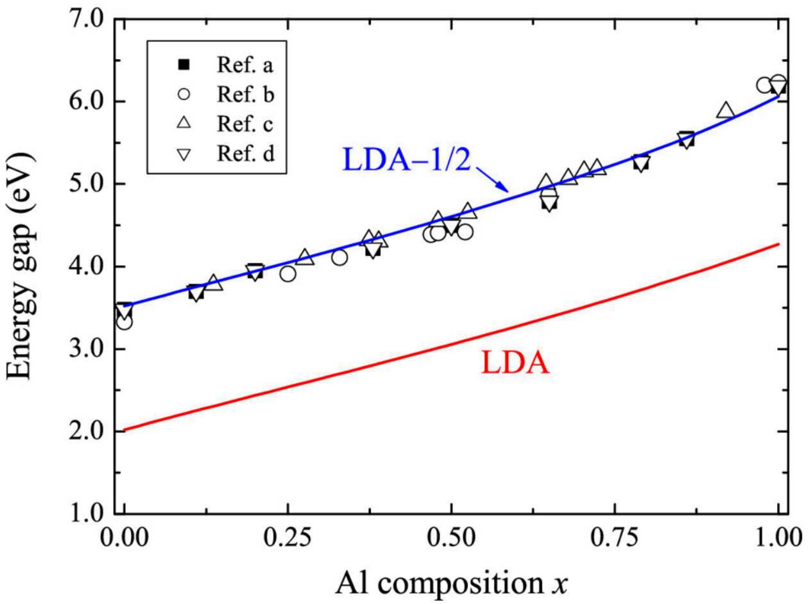
Simple Question

What is κ_{AlGaN}?

AlGaN Use in Power Electronics



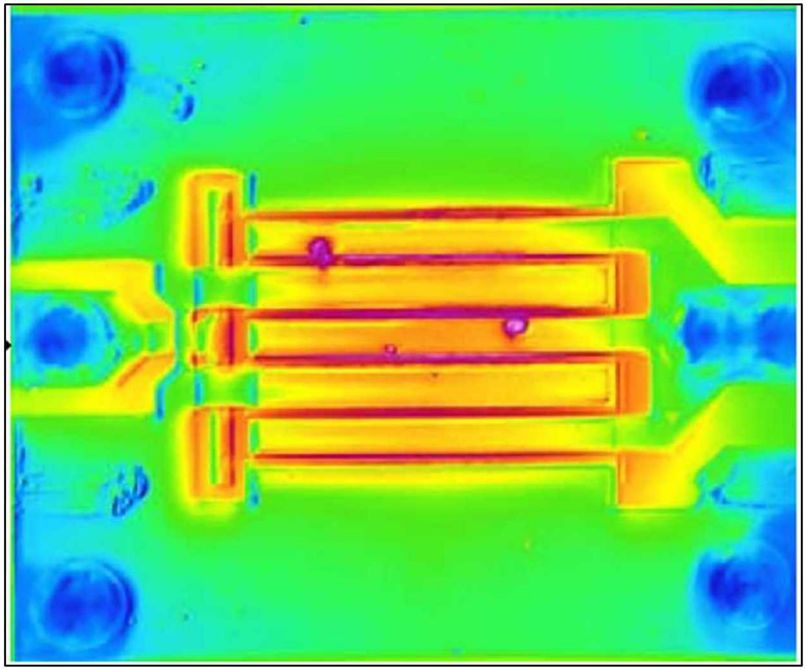
R. J. Kaplar et al. ECS J. Solid State Sci. Technol. 2017;6:Q3061-Q3066

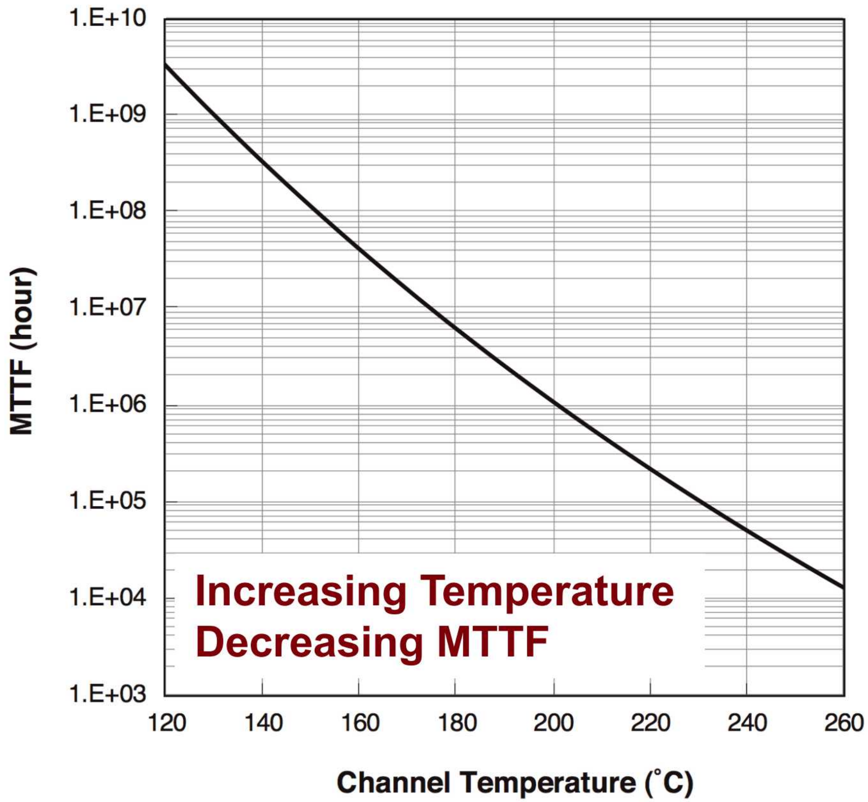


R. R. Pelá; C. Caetano; M. Marques; L. G. Ferreira; J. Furthmüller; L. K. Teles; *Appl. Phys. Lett.* 2011, 98

Advantage: Tunable ultra-wide band gap prevents breakdown

Temperature Impacts Performance & Reliability

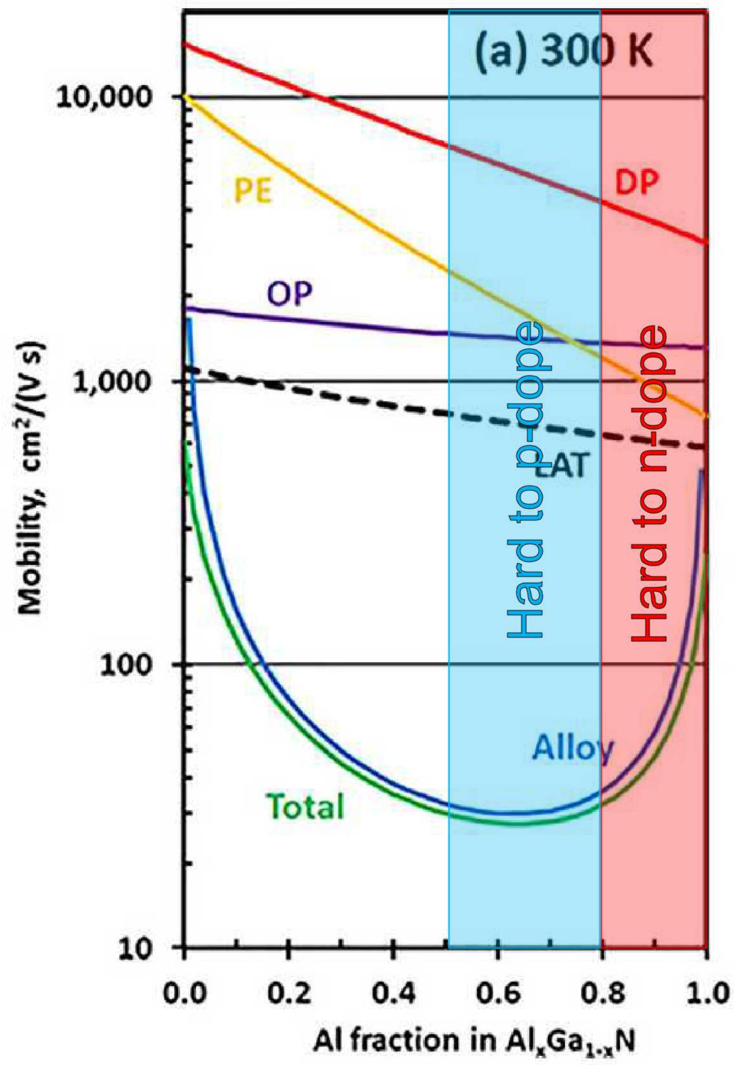


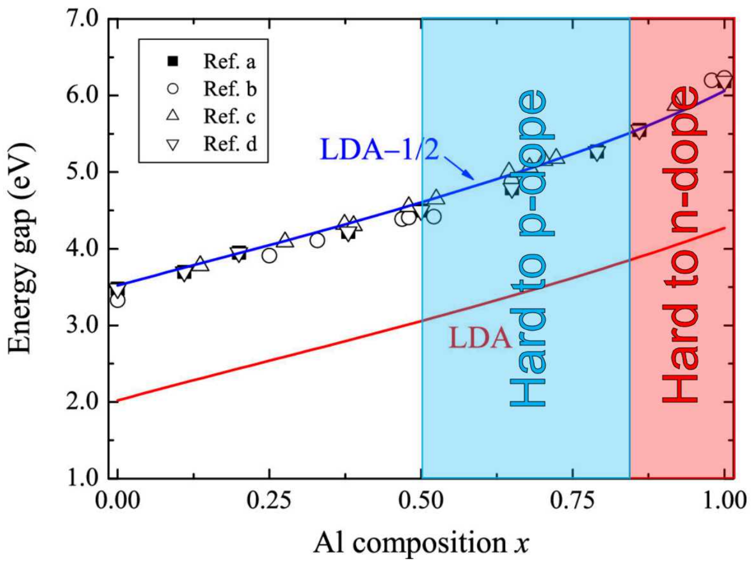


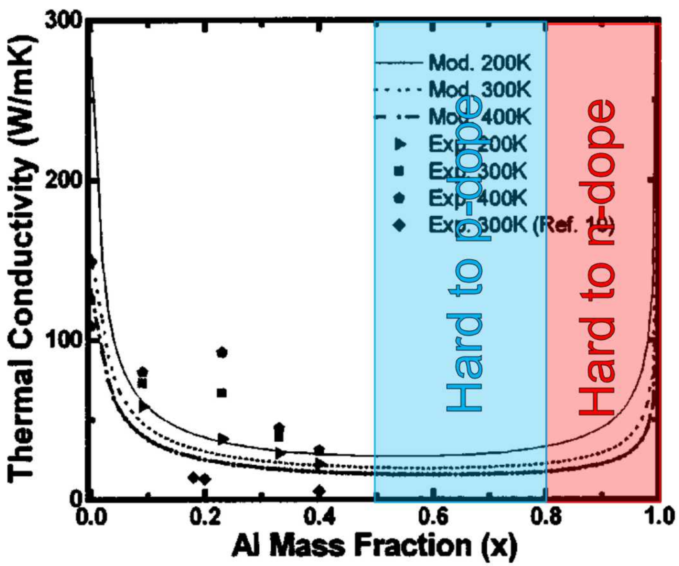
Disadvantage: Alloys have relatively low thermal conductivity

MTTF Figure: Yamaki et al. SEI Technical Review (76) 69 2013

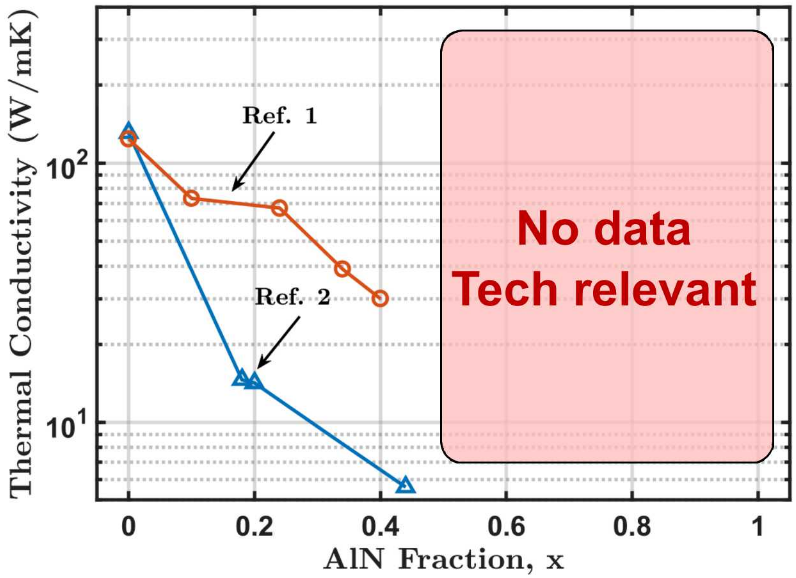
Optimize from several perspectives

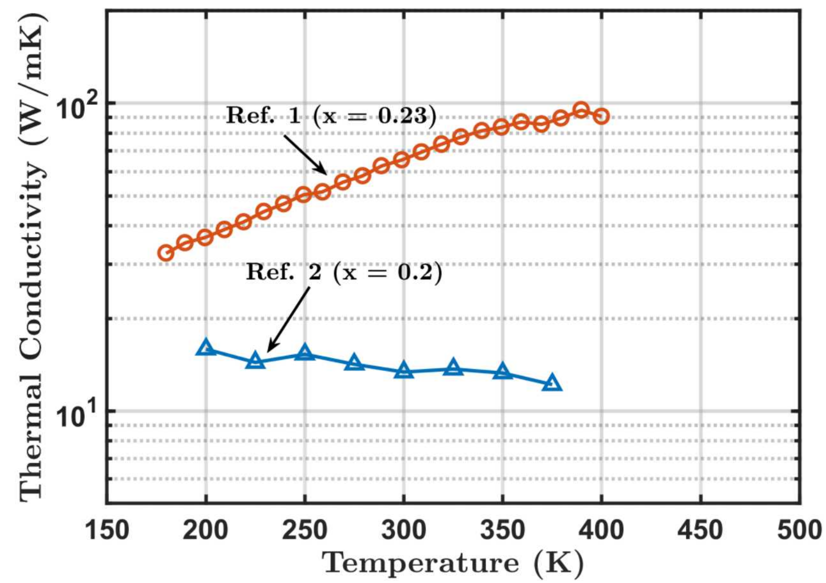






What is κ_{AlGaN}?





[1] Liu, W. & Balandin, A. *JAP*, 2005*, 97*
[2] Daly, B. *et al., JAP,* 2002*, 92*, 3820

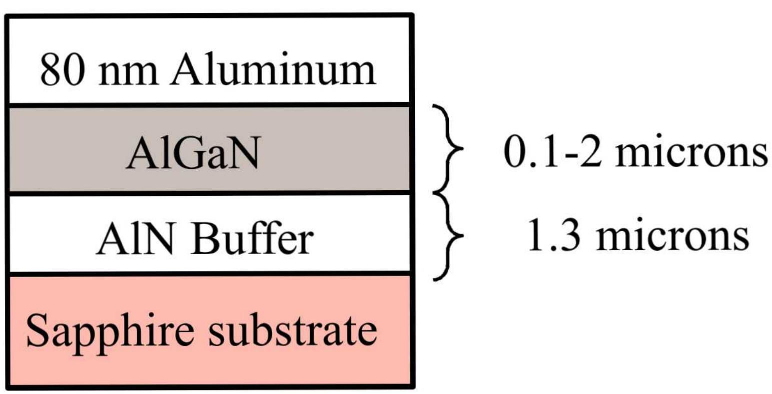
Literature Summary

1. Inconsistent magnitude of thermal conductivity
2. Contradictory temperature trends
3. Missing data for tech-relevant AlN-rich compositions

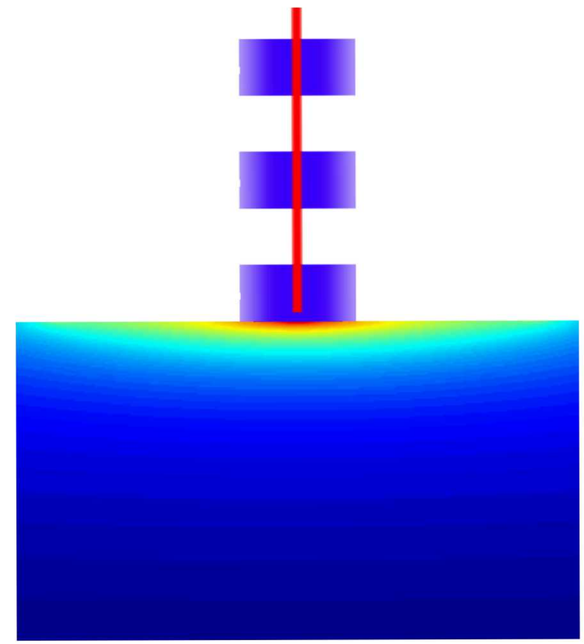
Method & Approach

AlGaN Synthesis

Vary: Thickness & Composition

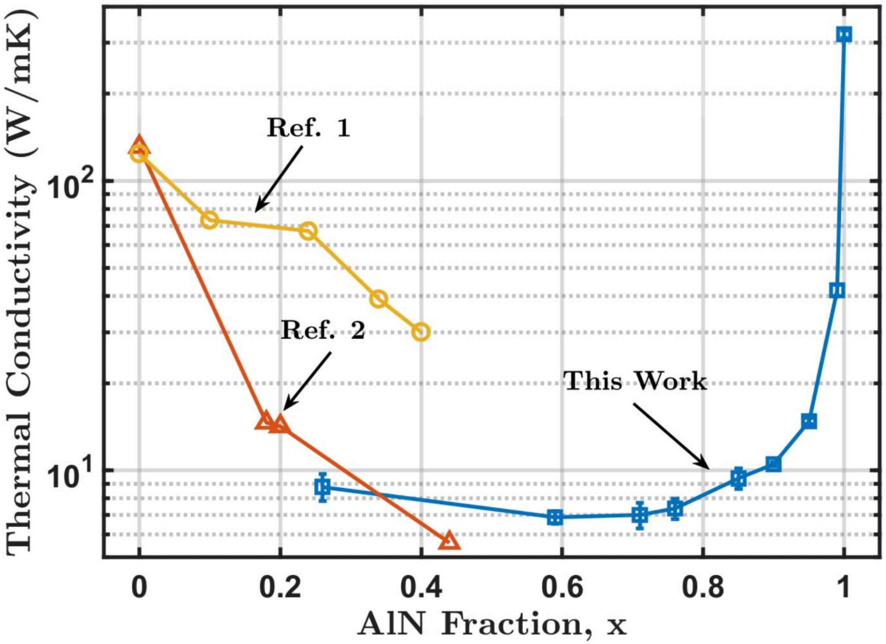


TDTR: Thermal Conductivity



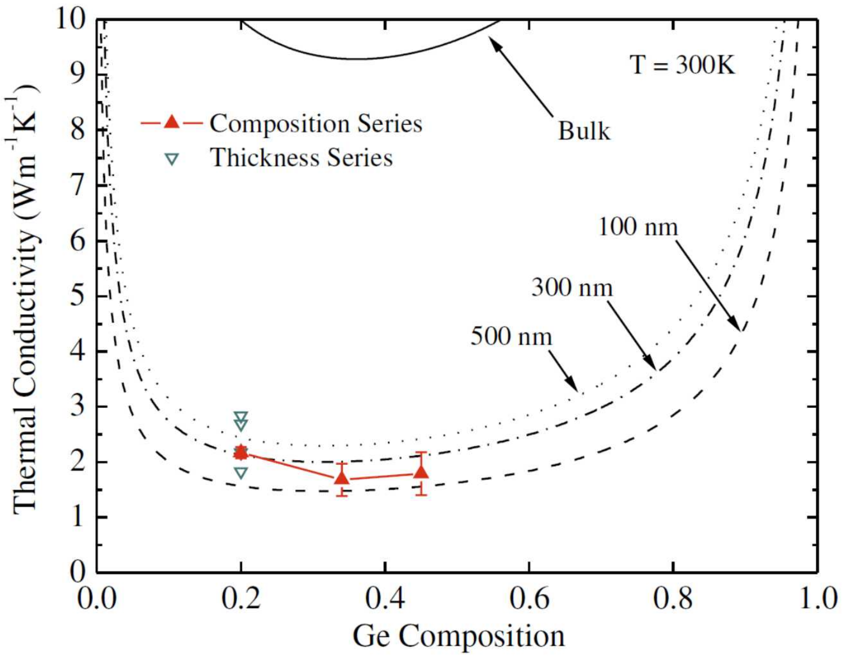
Random Alloying Reduces Conductivity

AlGaN



[1] Liu, W. & Balandin, A. *JAP*, 2005, *97*
[2] Daly, B. *et al.*, *JAP*, 2002, *92*, 3820

SiGe

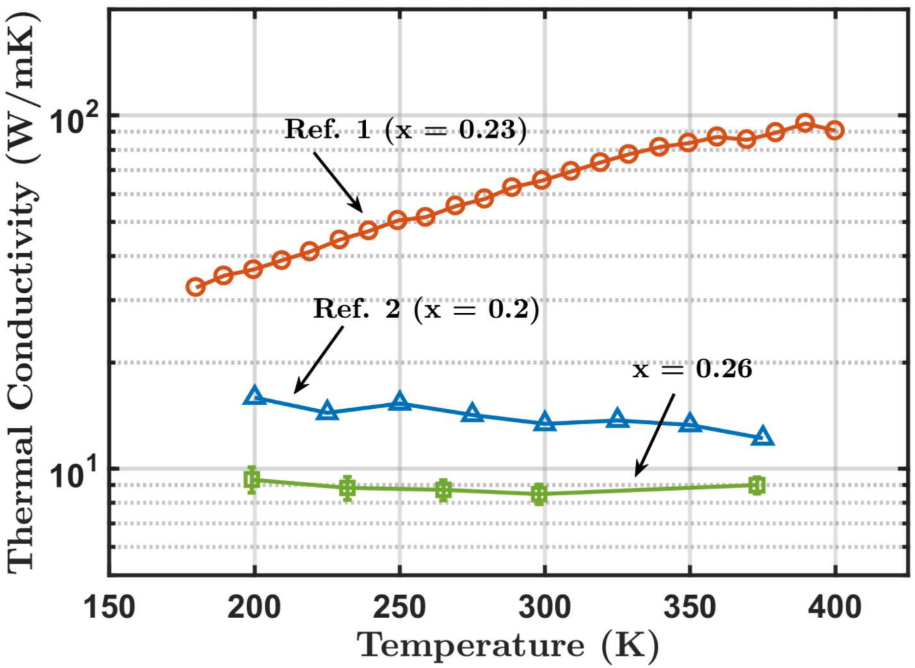


Cheaito, R. *et al.*, PRL., 2012, *109*, 195901

Composition Results

1. Observe typical bathtub shape of alloys with composition
2. Magnitudes on par with other alloys

Temperature identifies scattering mechanism



[1] Liu, W. & Balandin, A. *JAP*, 2005, *97*
[2] Daly, B. *et al.*, *JAP*, 2002, *92*, 3820

Specific heat

Scattering time

$$\kappa = \frac{1}{3} C v^2 \tau$$

velocity

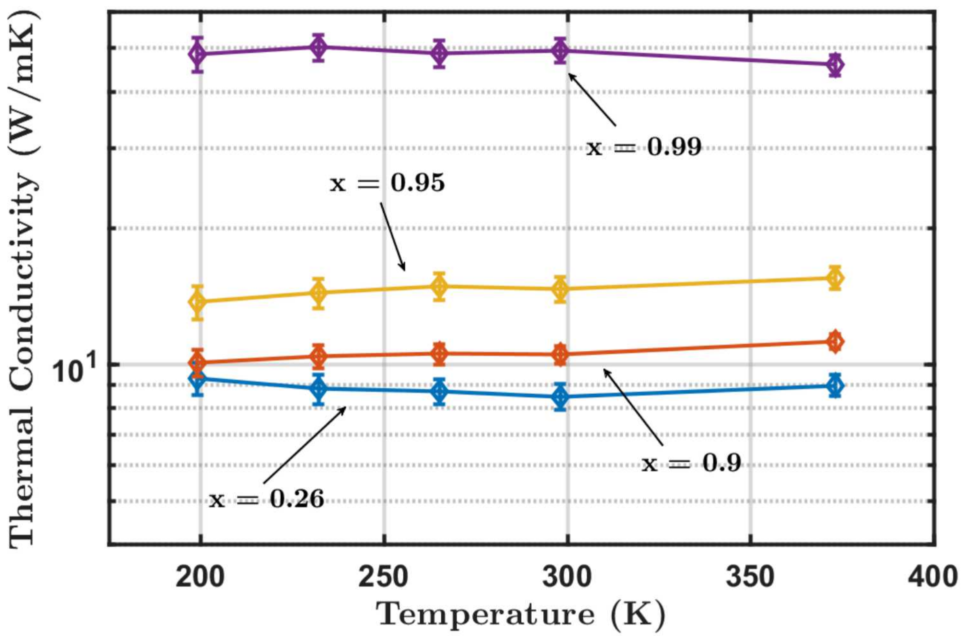
- Specific heat increases with T
- Scattering time decreases with T

Temperature Results

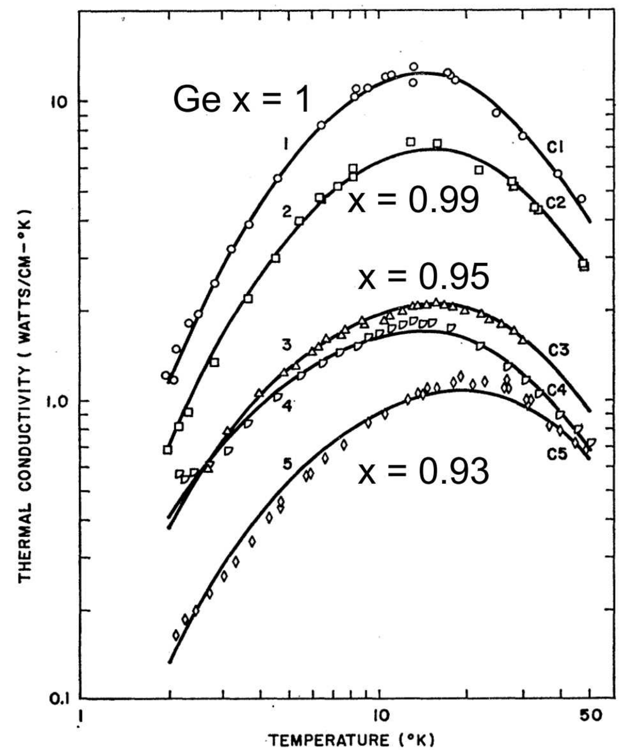
1. Observed typical negative or flat trend with temperature
2. Trends follow those expected for a random alloy

Temperature identifies scattering mechanism

AlGaN (d = ~1 um)



SiGe (d = ~3000 um)

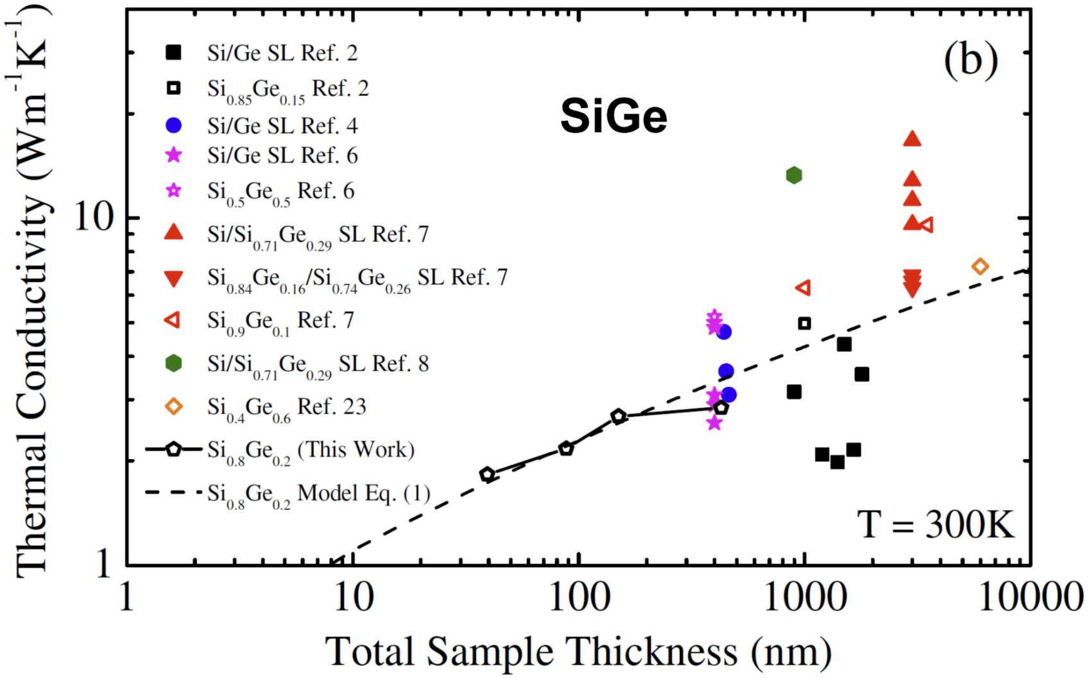


Toxen, A. M. *Phys. Rev.*,1961, *122*, 450-458

Temperature Results

1. Observed typical flat trend with temperature at all compositions
2. Flat trend due to both size and alloying effects

Alloying Increases Size Effects



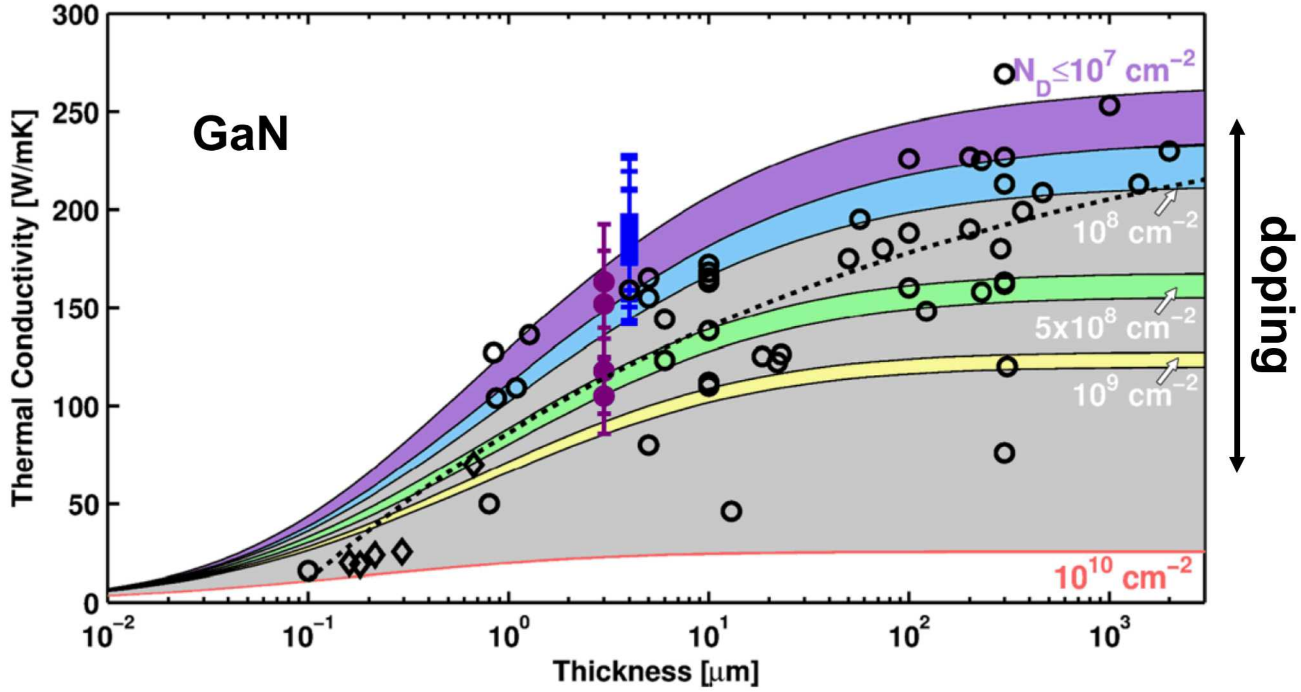
$$\tau_a = [x(1-x)A\omega^4]^{-1}$$

Cheaito, R. *et al.*, PRL., 2012, *109*, 195901

Size Effects

1. Alloy scattering affects high frequency modes
2. Thermal conductivity dominated by low frequency high MFP modes

Size Impacts Conductivity in Many Materials

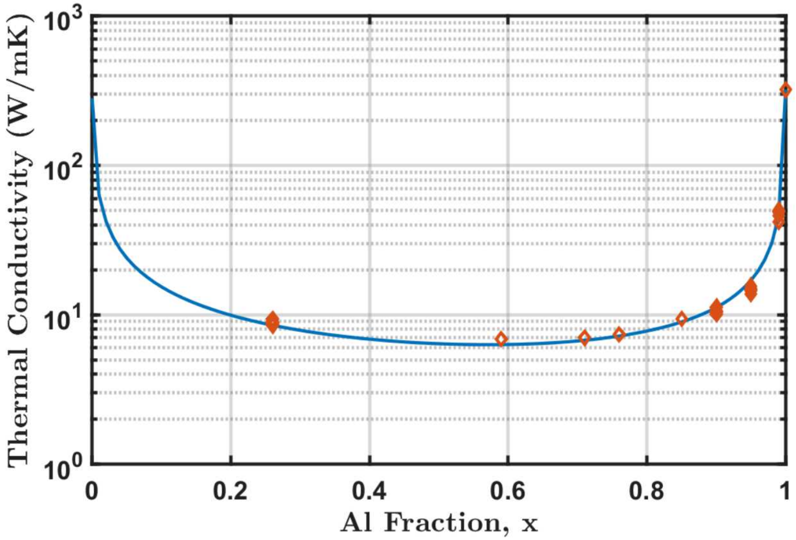


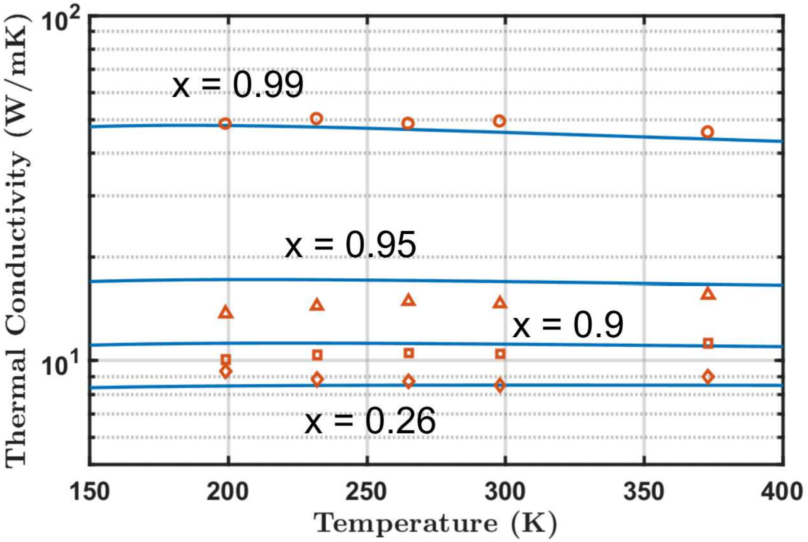
Beechem *et al.*, JAP, 2016, 120, *095104*

Size Effects

1. GaN conductivity varies by orders of magnitude depending on size
2. Bulk thermal conductivity not reached until **<u>100 microns</u>**

Used Model to Investigate Size effects

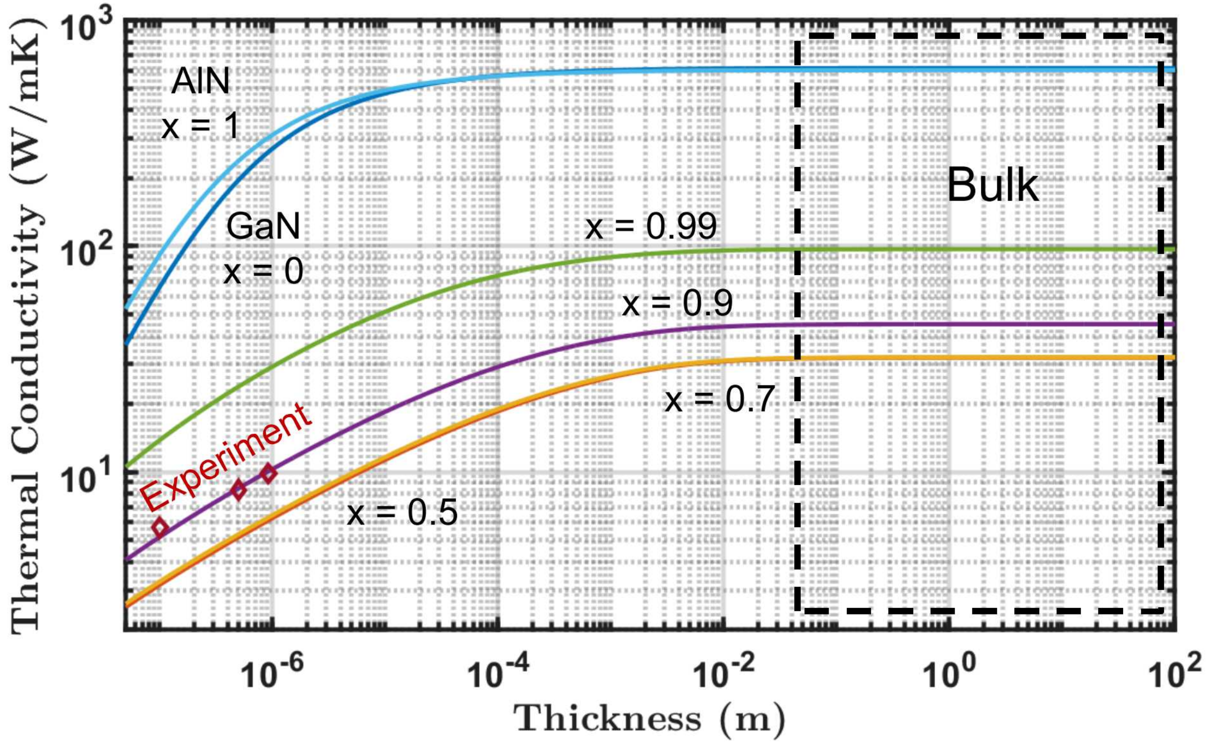




Model Fit

1. Fit Debye Model to our temperature and composition dependent data
2. Used scattering rate parameters to investigate size effects

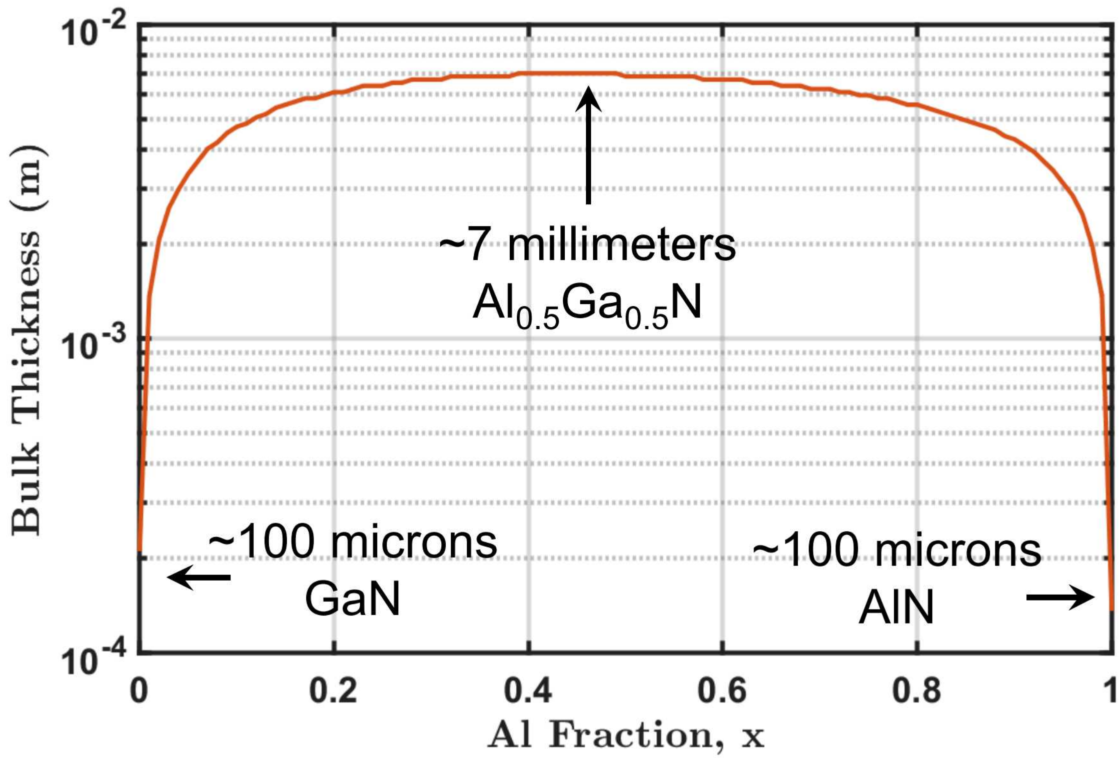
AlGaN Strongly Dependent on Size



Size Effects

1. AlGaN conductivity varies by ~1 order of magnitude with size
2. Experiment accurately matches model

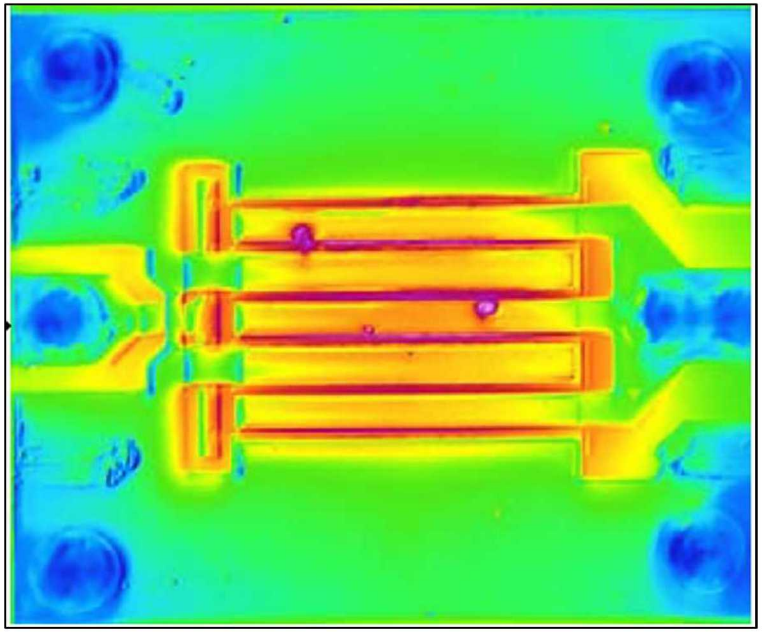
What is Bulk in AlGaN?

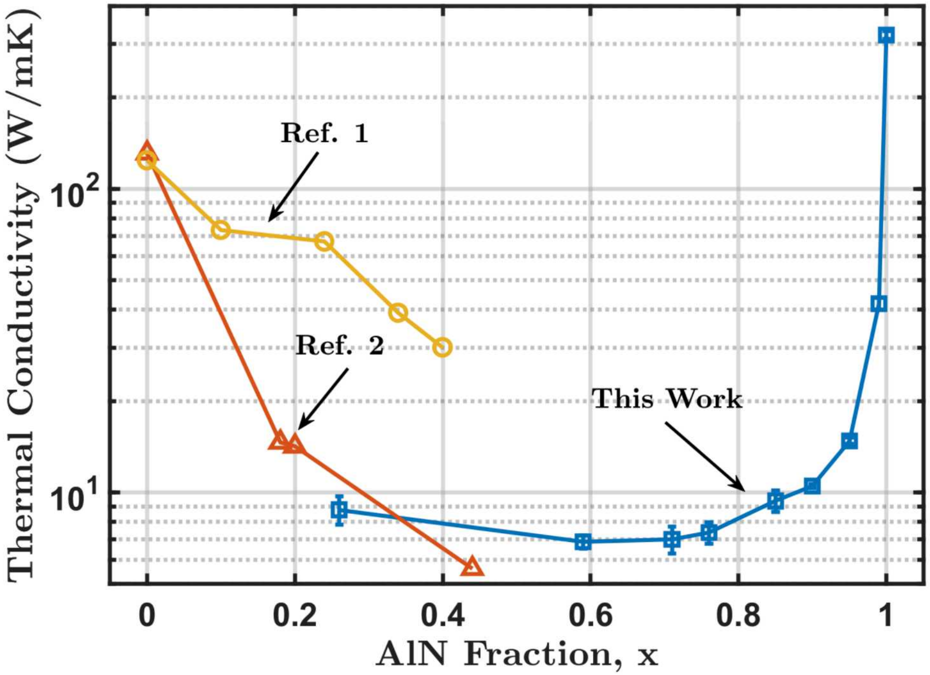


Size Effects

1. Bulk thickness depends on composition (~2 orders of magnitude)
2. Bulk thermal conductivity not reached until **7 mm** in 50/50 AlGaN

Take Home Message





1. AlGaN behaves as expected for a random alloy
2. Thermal Conductivity of Alloys strongly dependent on size
3. Debye model can be used to accurately predict thermal transport

Better Material, Better Property, Better Device

Technique: Time Domain ThemoReflectance (TDTR)