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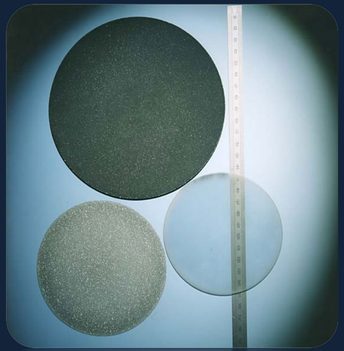
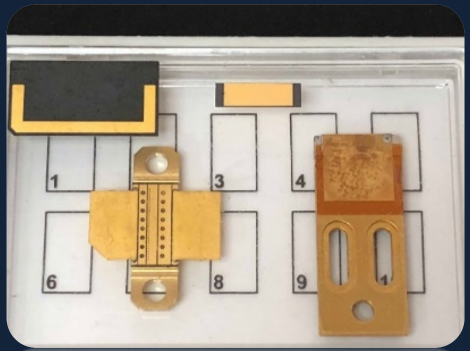
Step change thermal management of RF devices using CVD diamond

Commercially available heat spreaders





July 2020

70 years of turning a natural curiosity to an engineered material

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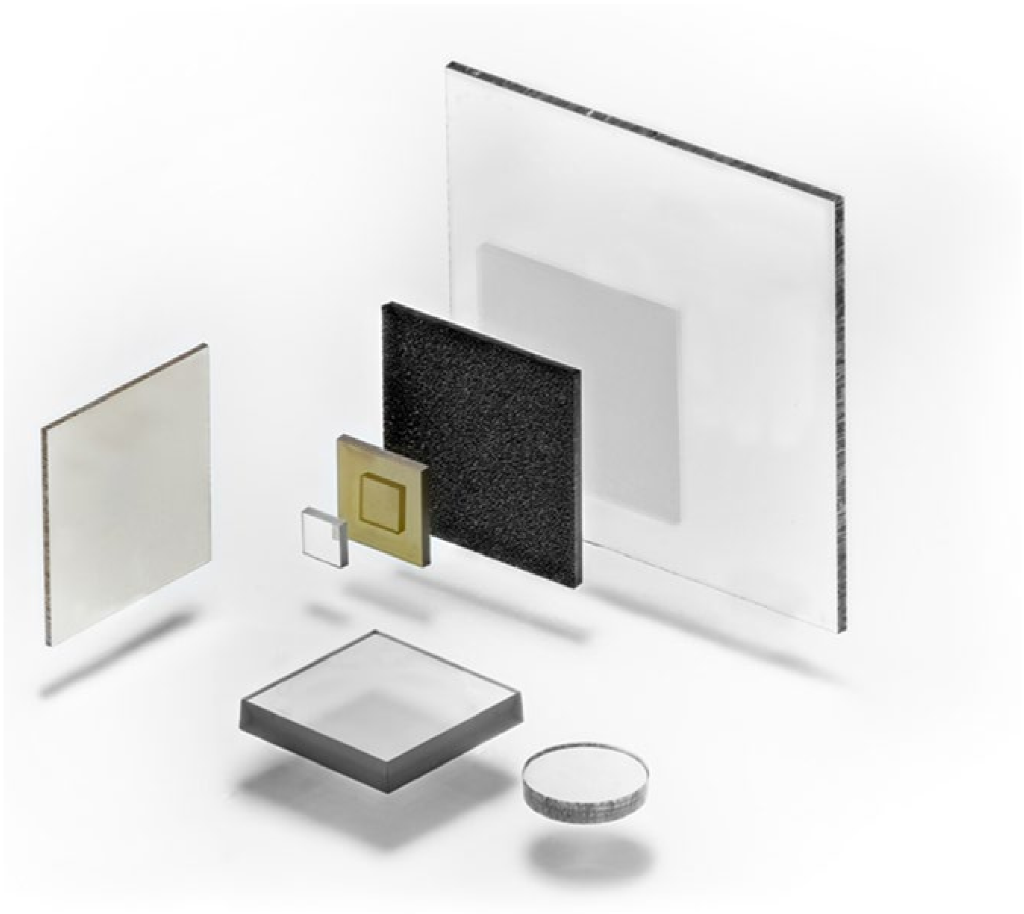

1. Motivation

Applications for GaN devices

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Discrete HEMTs

Defense Apps
(eg Radar, EW,
Avionics)

Energy-
efficient
wireless
networking

MMICs & Hybrid PAs

More efficient
Inverters for
PV/Wind

More efficient
Inverters for
Hybrids/EVs

Switches & Diodes

New & Efficient
Weather & Comm.
Satellites

More powerful
smartphones

GaN HEMT thermal management

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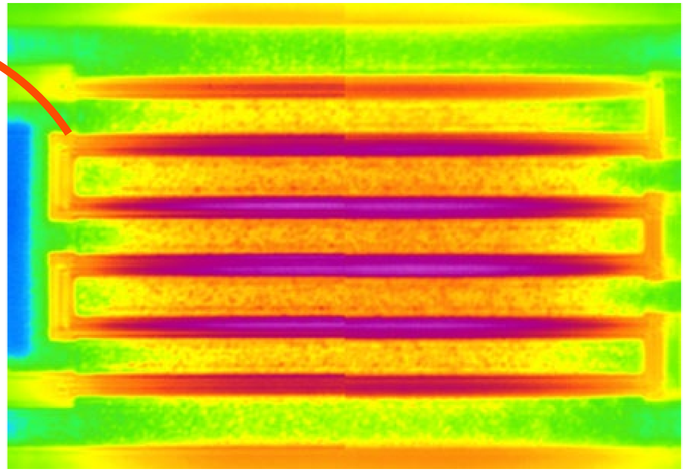
GaN HEMTs enable a 5x increase in RF power density w.r.t. GaAs

Reduced area and RF losses
(Substrates: GaAs = 55 W/mK, versus SiC~420W/mK)

http://www.mpdigest.com/issue/Articles/2013/Feb/TriQuint/

GaN-on-SiC is power density is thermally limited!

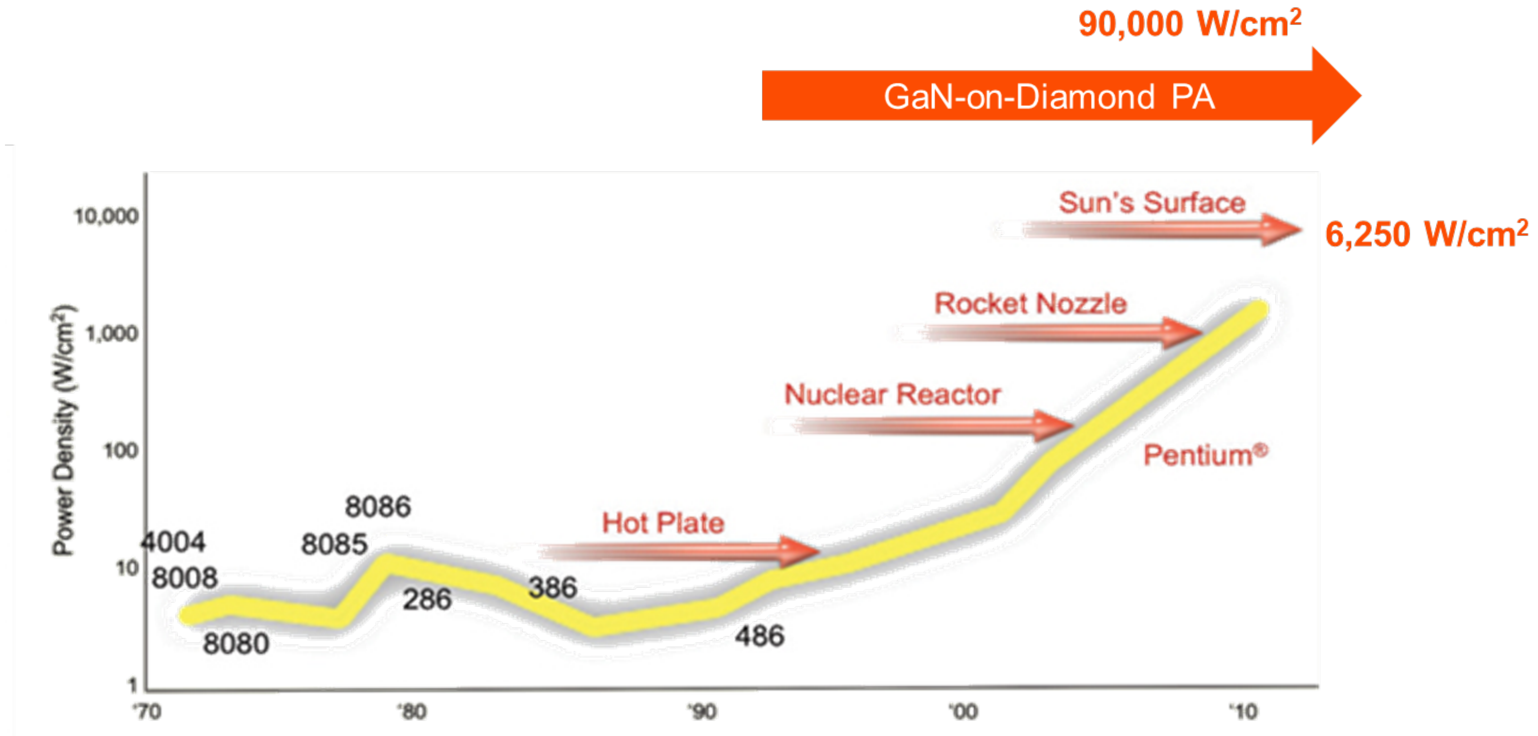


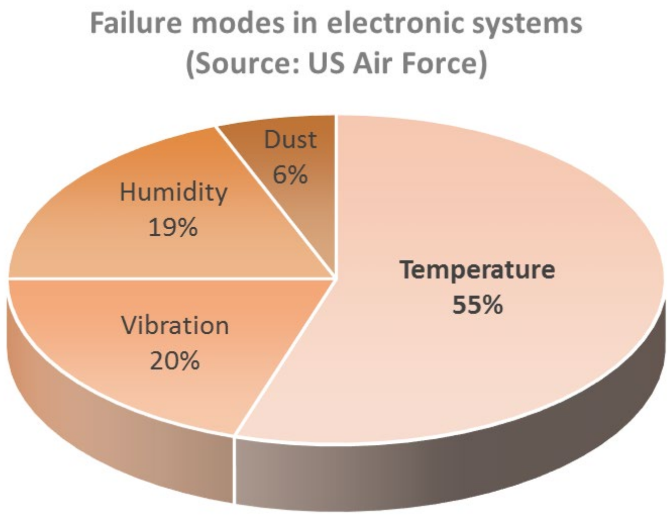
GaN HEMT thermal image

Higher power densities require improved near junction thermal transport

Extreme power densities in modern RF devices

Power densities for GaN devices is rapidly increasing and temperature is a major failing mode





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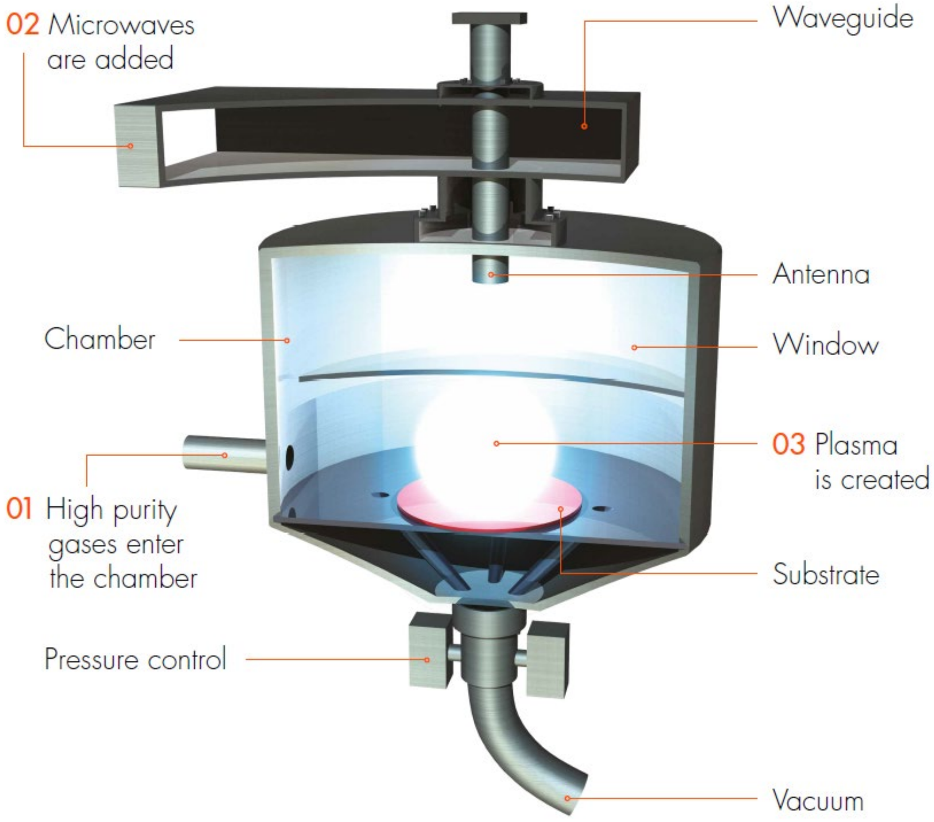
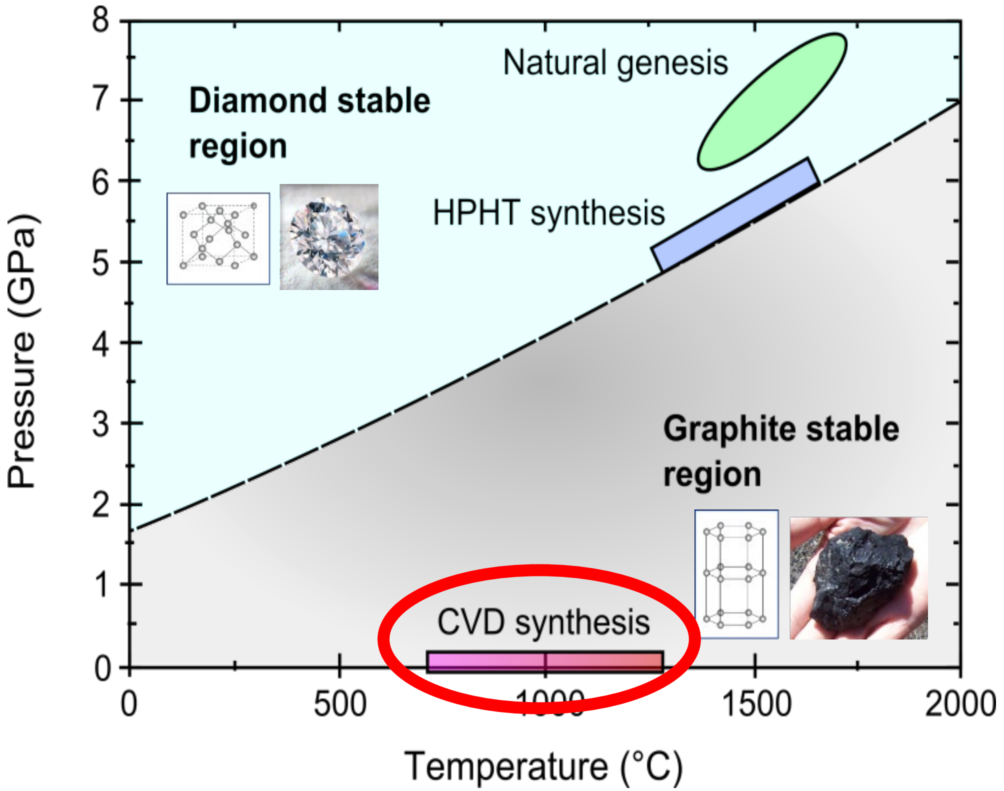
2. CVD diamond materials

Chemical vapour deposition (CVD)

Grow under meta-stable conditions for diamond





CVD growth: Polycrystalline

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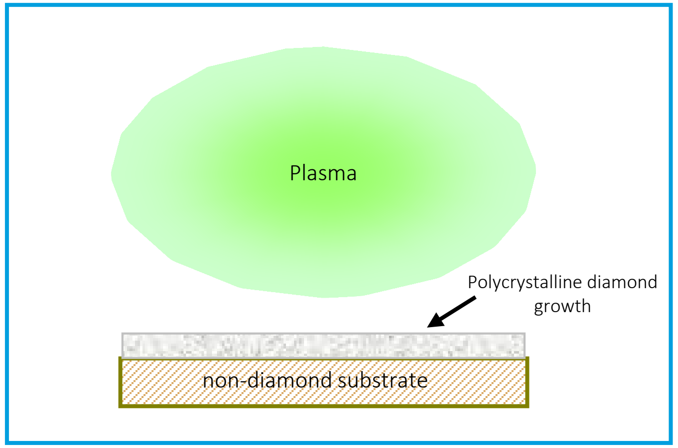
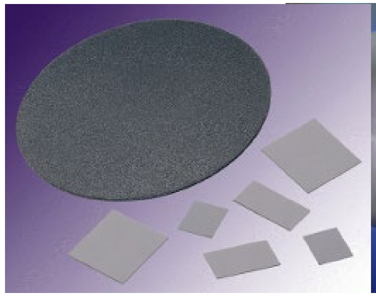
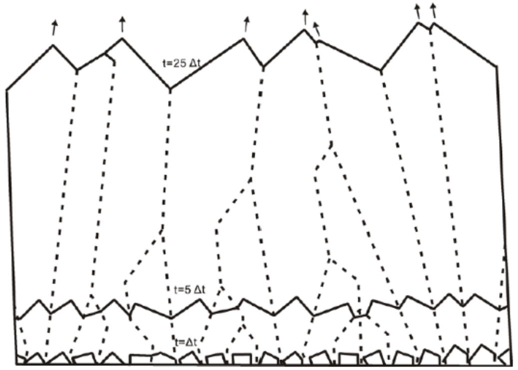
Non-diamond substrate → polycrystalline diamond growth



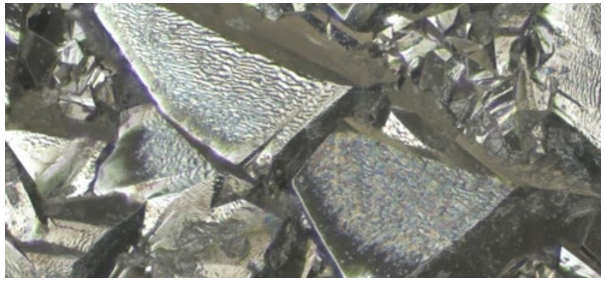


150 mm diameter & 4 mm thick

van der Drift growth model



- Initial diamond nuclei are randomly oriented
  - Competitive grain growth ensues: Fastest growing grains dominate
  - Grains size ~5-10% of thickness



Measuring bulk and interface conductivity

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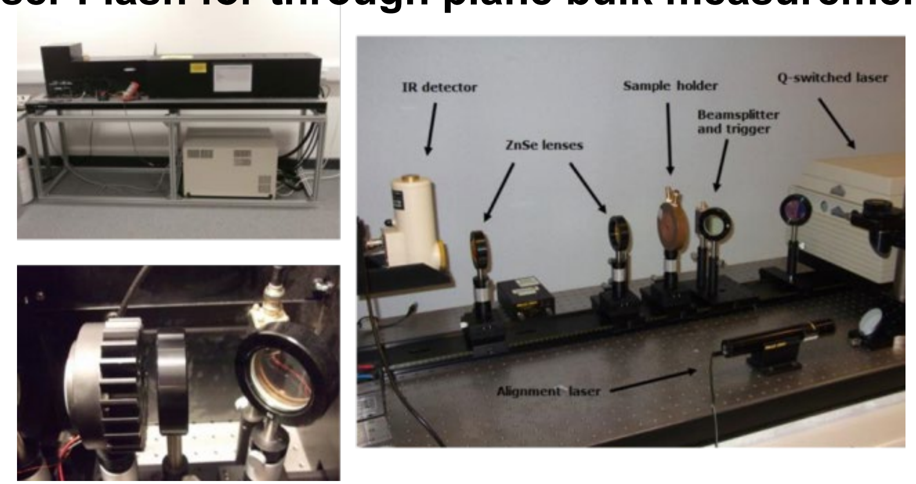
Laser Flash for through plane bulk measurement



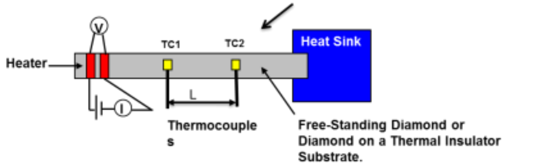
Heated Bar for in-plane bulk measurement

The in-plane thermal conductivity of the diamond is calculated, by using simple Joule heating thermometry *[1]*.

1. Thermal resistance is calculated by: $R = \Delta T/Power$
2. Thermal conductivity is calculated by: $k = L/RA$

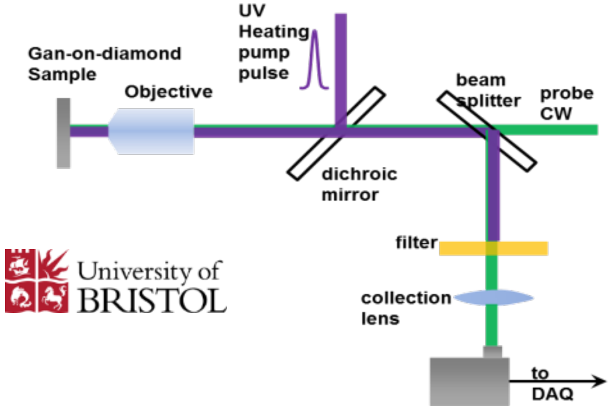
Where:
TC1 (thermocouple 1 reading): Temperature of the spot closer to heater
TC2 (thermocouple 2 reading): Temperature of the spot closer to sink
L: The fixed distance between the two thermocouple tips
A: Cross sectional area of the diamond strip
Power (dissipated power) = IV (from measured values)
ΔT (differential temperature) = TC1-TC2 (from measured values)

The basic layout of the measured sample, heater, thermocouples and heat-sink



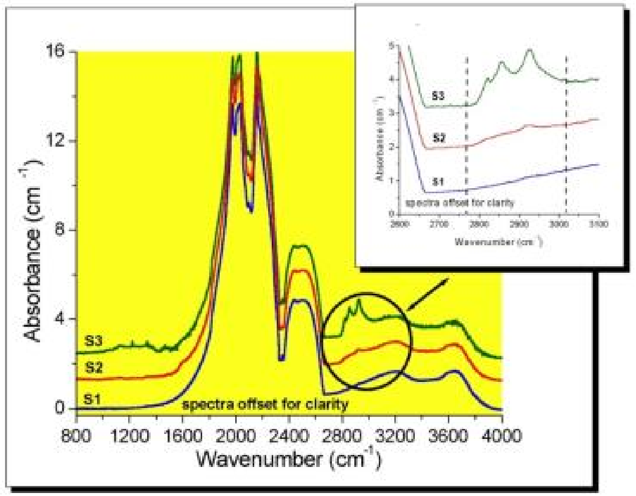
*[1] S.D. Wolter *, D.-A. a, Borca-Tasciucb, G. Chenb, N. Govindarajua, R. Collazoa, F. Okuzumia, J.T. Praterc, Z. Sitara, "Thermal conductivity of epitaxially textured diamond films"," Diamond and Related Material s 12 (2003) 61-64*

Transient thermo-reflectance technique for TBR

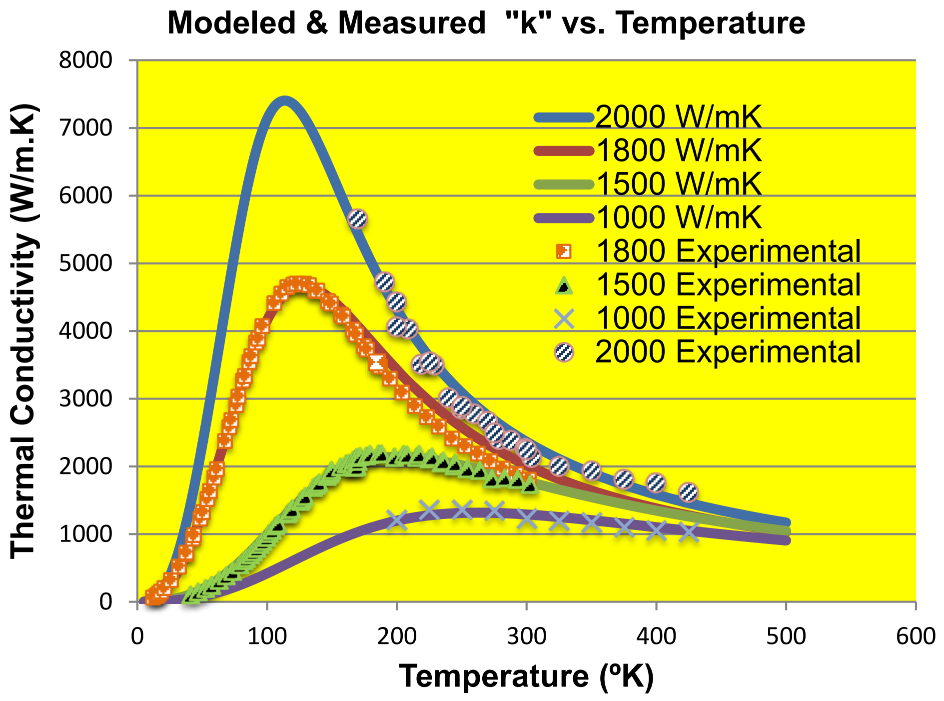


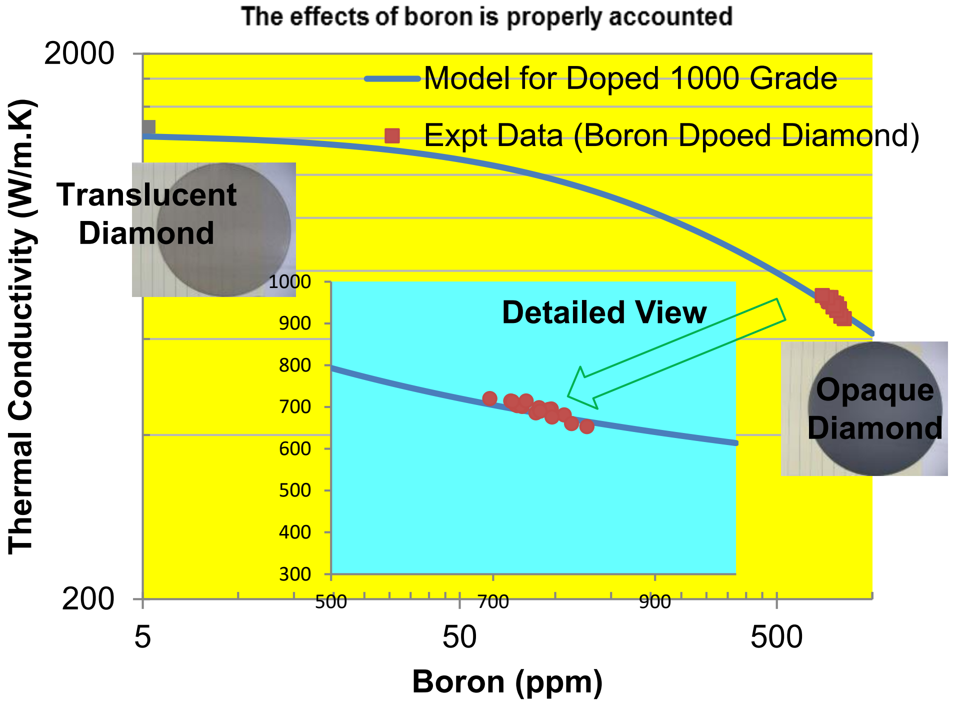
University of BRISTOL

FTIR for through plane bulk measurement



Comparison of model & experimental data





Measured experimental data used to verify the model

Material Grade	Nitrogen (ppm)	Dislocation Density (cm^{-2})	Grain Size (micrometers)	C-Vacancies (ppm)
Optical (711 µm)	0.1-0.4	10^8	120-160	9-13
1800 W/mK (600 µm)	2.0-5.0	10^8	100-140	20-30
1800 W/mK (250 µm)	2.0-5.0	10^8	30-70	20-30
1500 W/mK (250 µm)	12.0-17.0	10^8	30-70	20
1000 W/mK (250 µm)	0.1-0.3	10^11	20-30	22-24

CVD diamond heat spreaders

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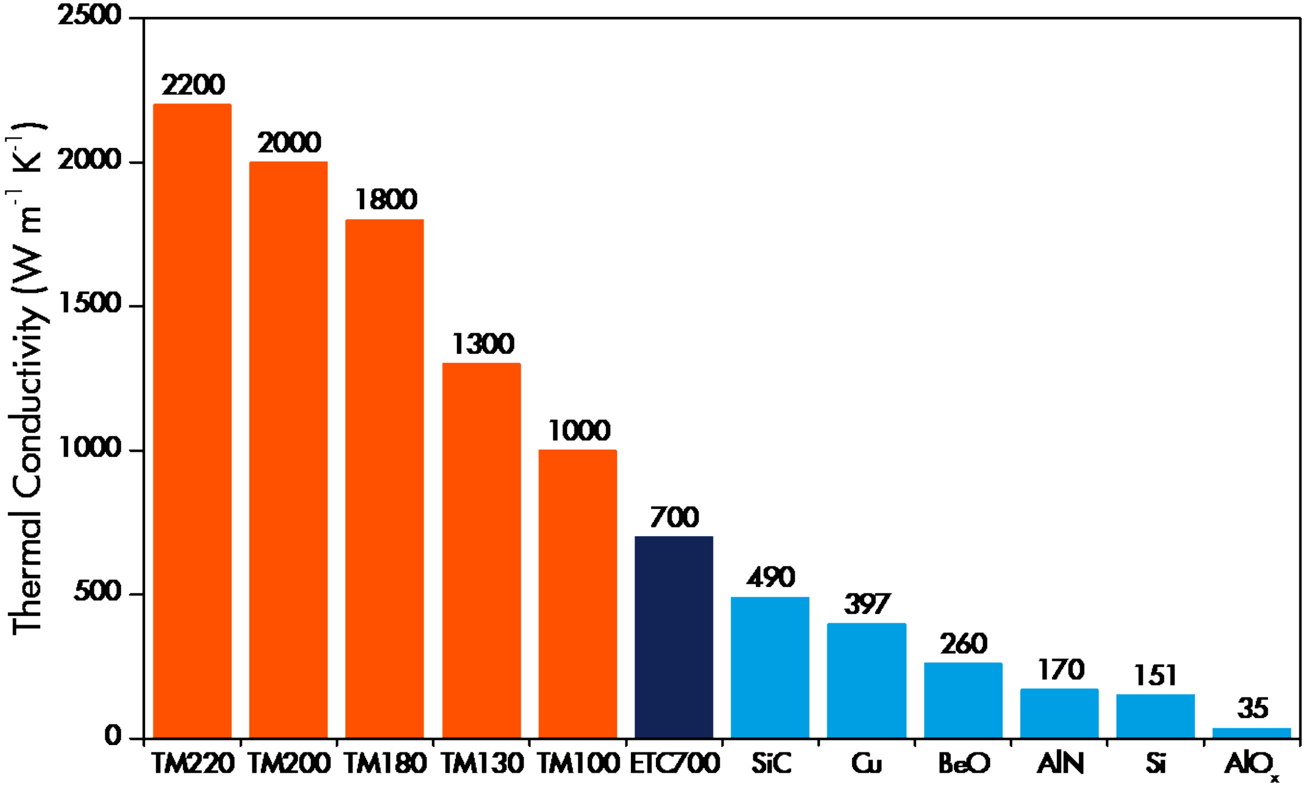

Diameters up to 140 mm & thicknesses of 0.3 to 4 mm

- Controlled synthesis and materials characterization enables different thermal grades
- Thermal conductivity controlled in the range 700 – 2000 W m^{-1} K^{-1}
- Great than factor 2 thermal conductivity than: GaN:SiC, Cu and Si

Delivering a thermal solution – E6 FEA capability

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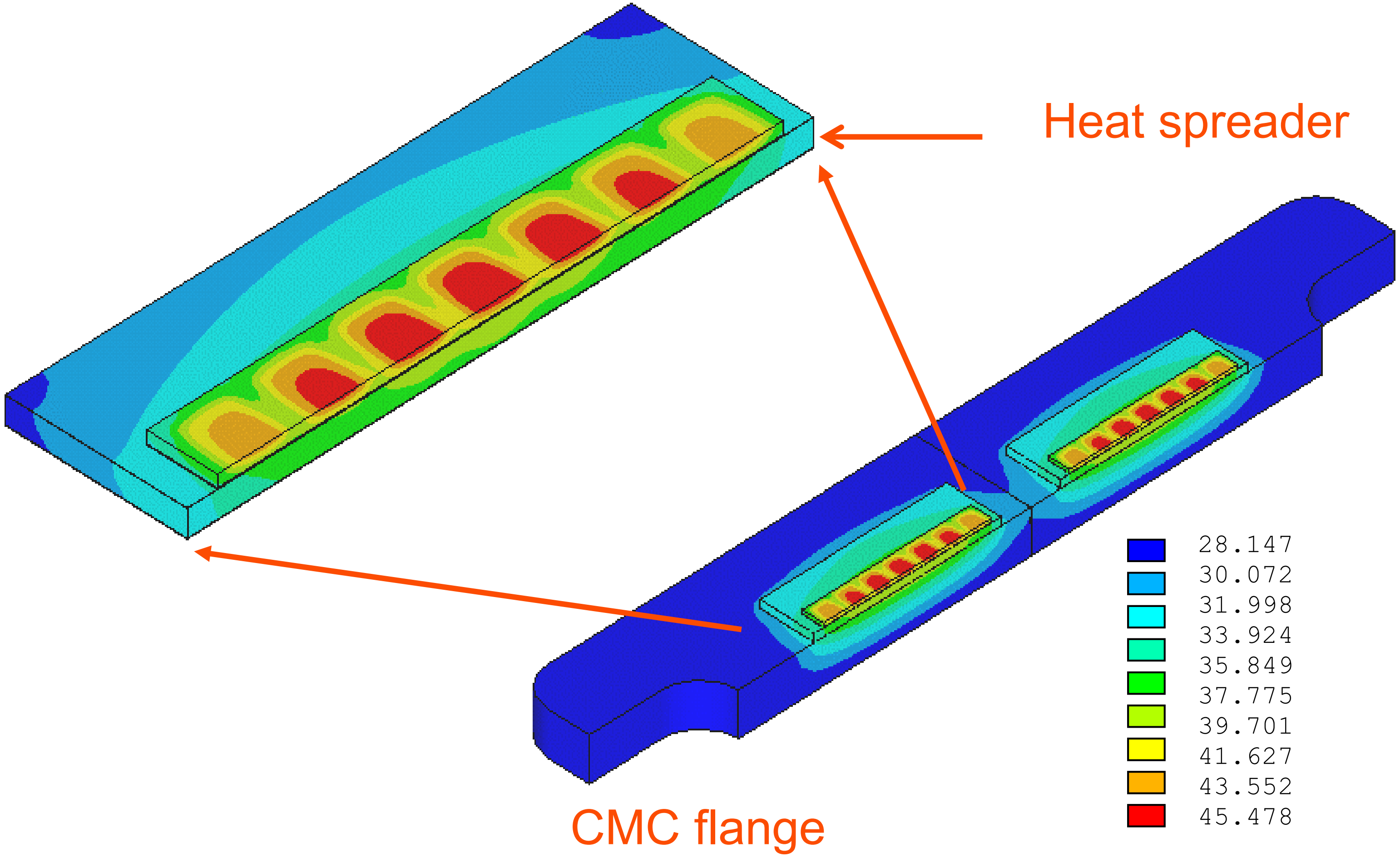
The thermal pathway

- Heat spreader characteristics
  - Grade, dimensions TC, CTE
- Heat sink characteristics
  - Material, TC, CTE
- Device characteristics
  - DC, HF, pulsed, continuous
- Attachment method
  - Glues, solder / braze, clamps and pastes
- System requirements
  - Operating temperature

Finite element analysis tools

- Solving the thermal puzzle



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Contact us to find out more

E ustechnologies@e6.com
T +1 408 986 2400
W e6.com