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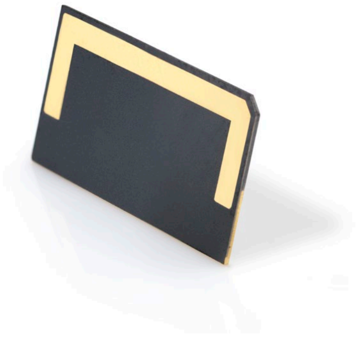
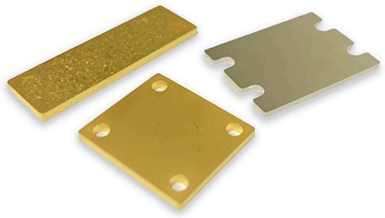
Case studies

Step-change thermal management of radio frequency (RF) devices using chemical vapour deposition (CVD) diamond

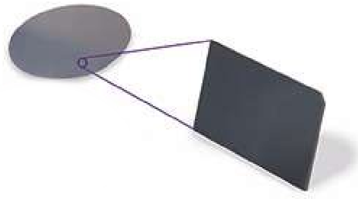
Thermal polycrystalline diamond



Diafilm™ TM



Cu-Diamond



Diafilm™ ETC700

Simple introduction – a stack of thermal resistors

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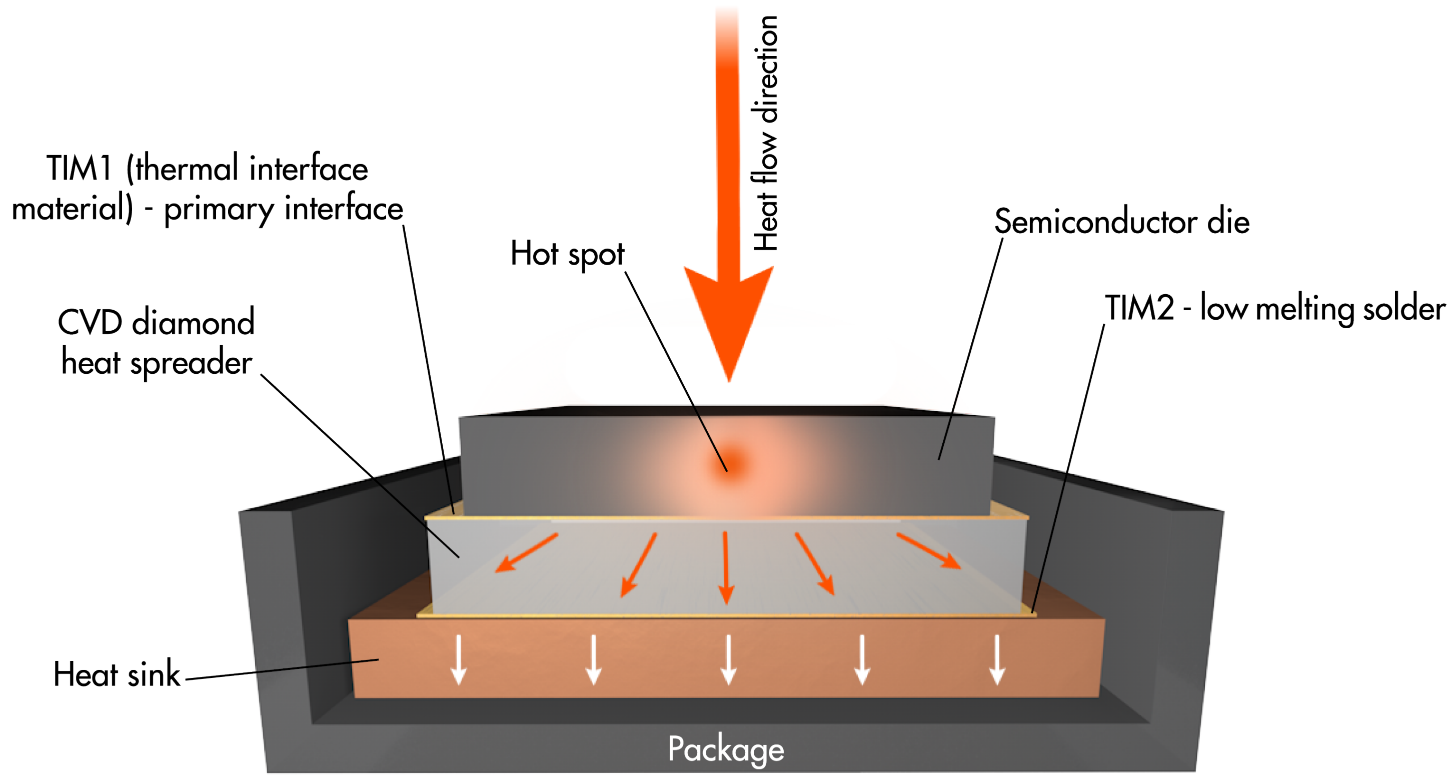

Typical package geometry with a CVD diamond mounted module

- Heat spreader reduces peak device temperature by reducing heat flux density
- In a RF circuit there are two components with high power density:
  - Thermal management of **active** device: CVD diamond heat spreader for high power amplifiers - high-efficiency multistage plasma thrusters (HEMPTs)
  - Thermal management of **passive** device: CVD diamond substrate for high power RF resistor

CASE 1 - Novel metallisation scheme (Cr) compared with conventional (Ti-Pt) reduce Tj of PA by 25%

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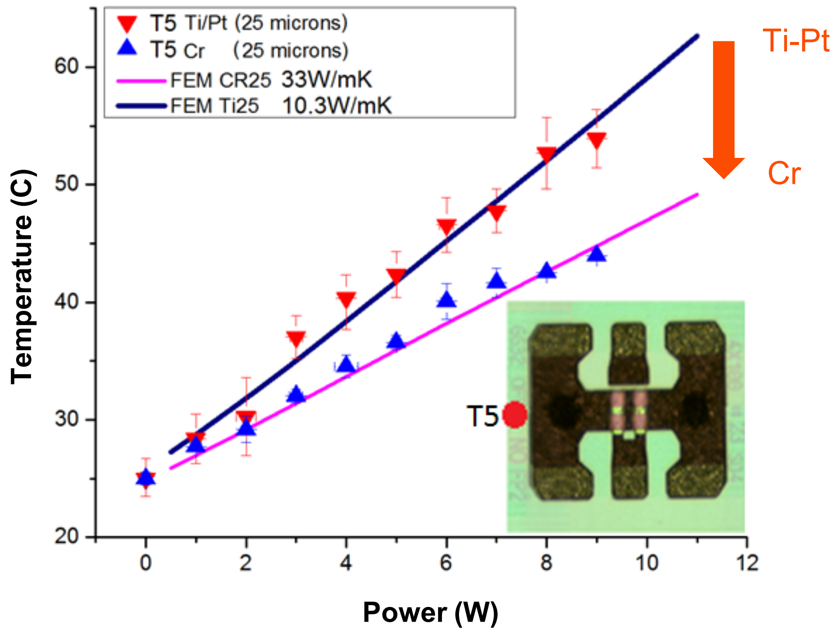
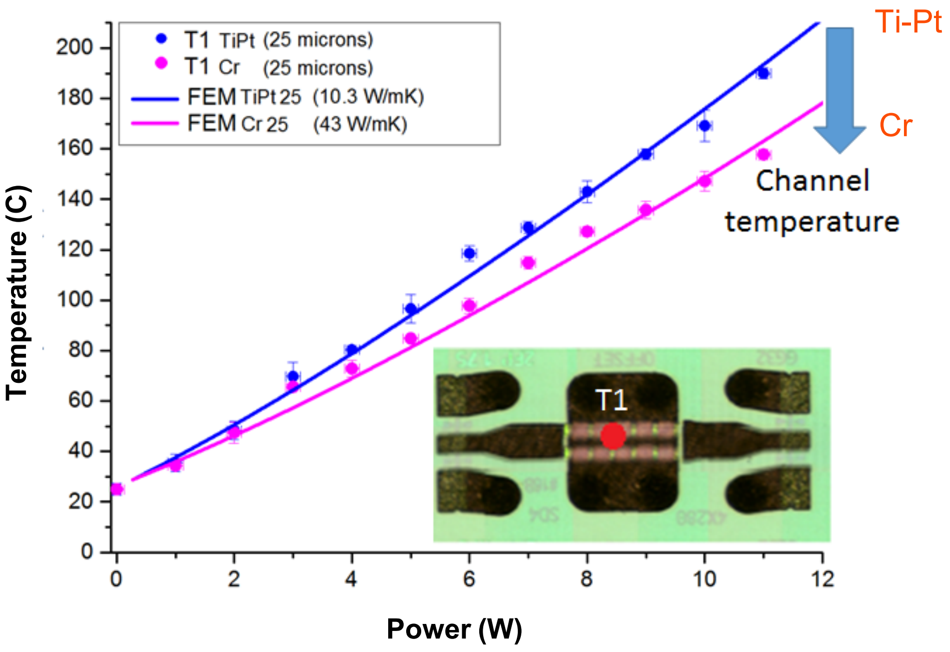
- A new metallisation scheme (Cr) has improved the thermal conductivity of the die-diamond attach by 3-4 times – compared to using Ti-Pt
- With Cr, channel temperature drops by 25% (for big devices e.g. high-power PAs), and 13% (for small devices) compared to using Ti-Pt

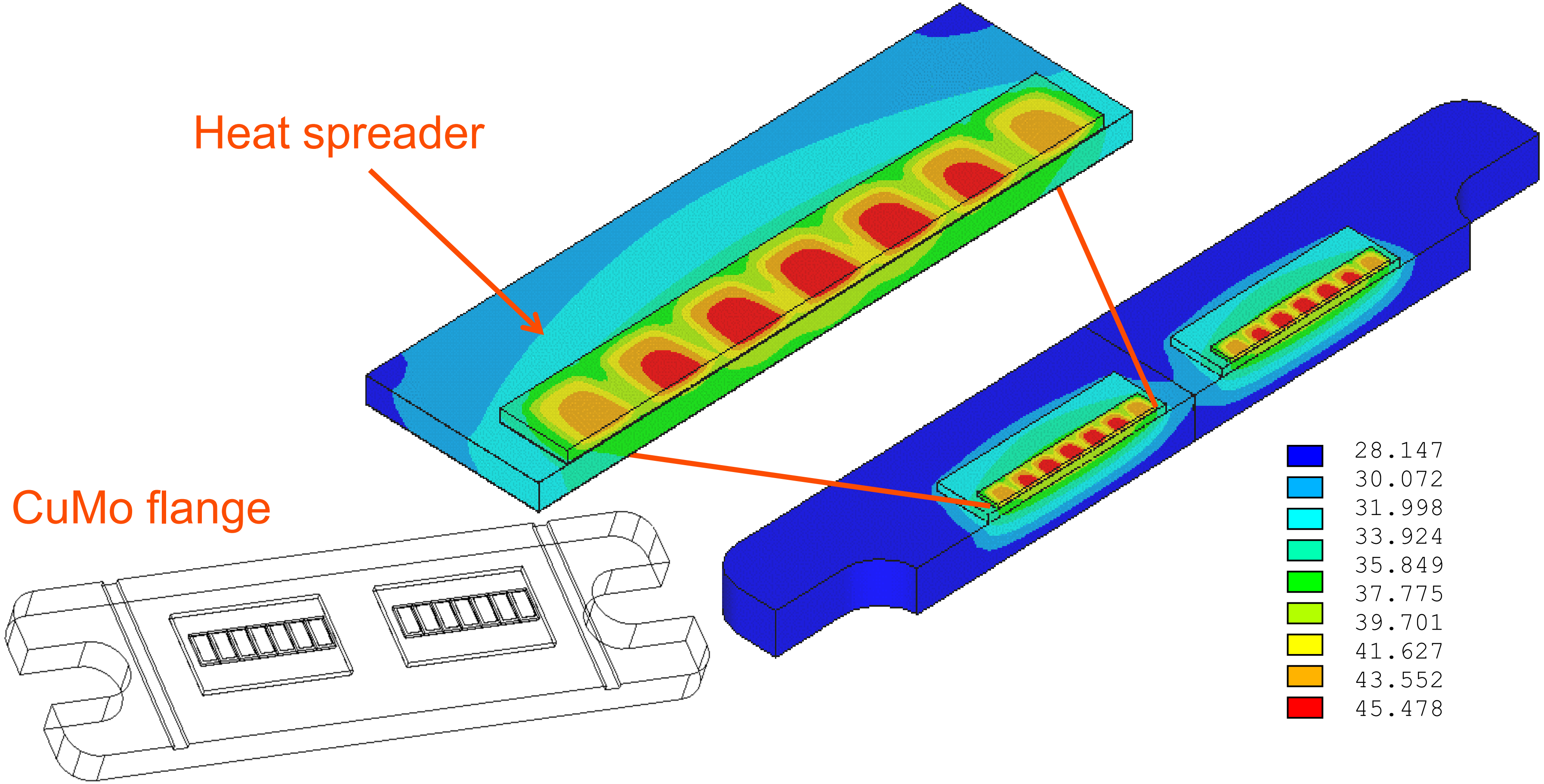
Tj of Big Device (High Power Amplifier)



Tj of Small Device



CASE 2 - CVD diamond for an RF gallium arsenide (GaAs) package



Need to replace beryllium oxide (BeO) for a combination of toxicity and thermal performance issues

CASE 2 cont. - CVD diamond for an RF (GaAs) package

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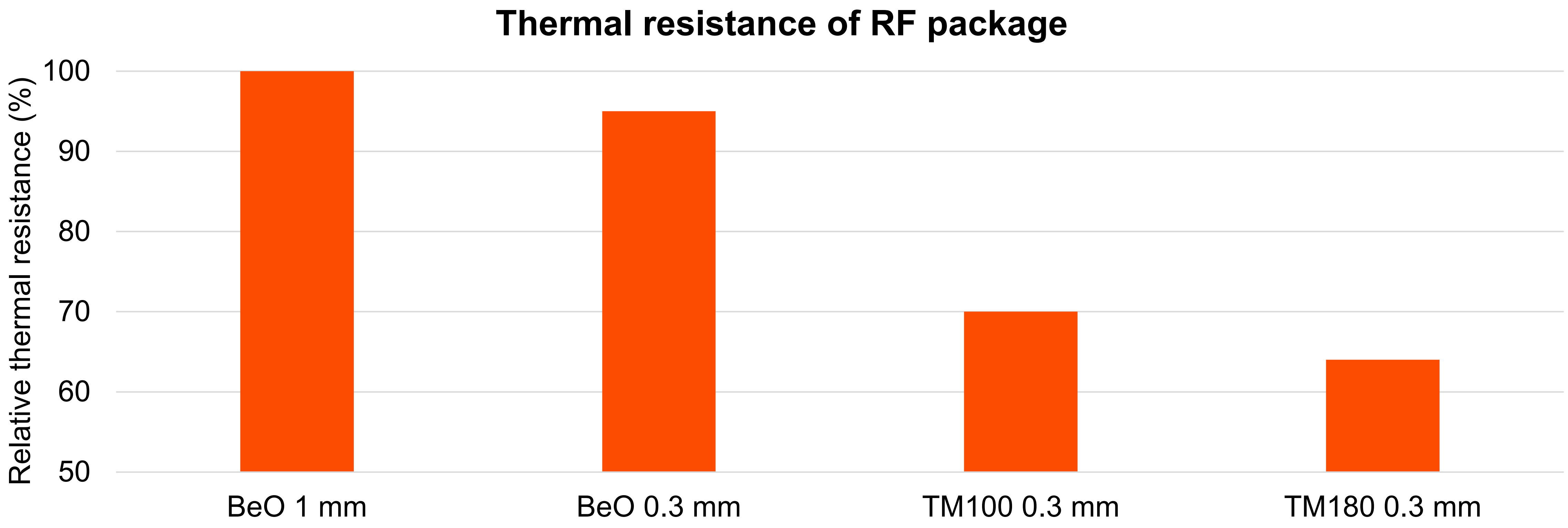

Significant thermal resistance reduction in moving to synthetic diamond heat spreader

CASE 2 cont. - CVD diamond for an RF package

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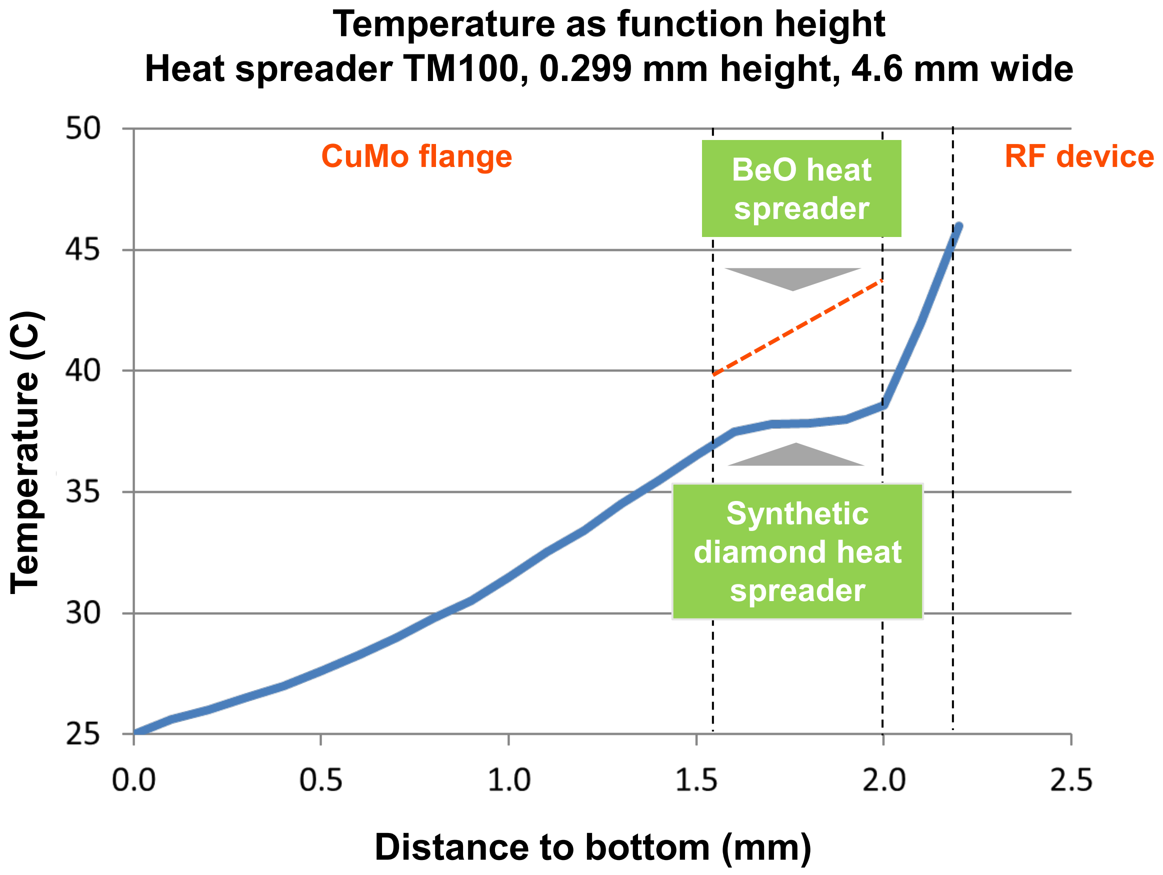

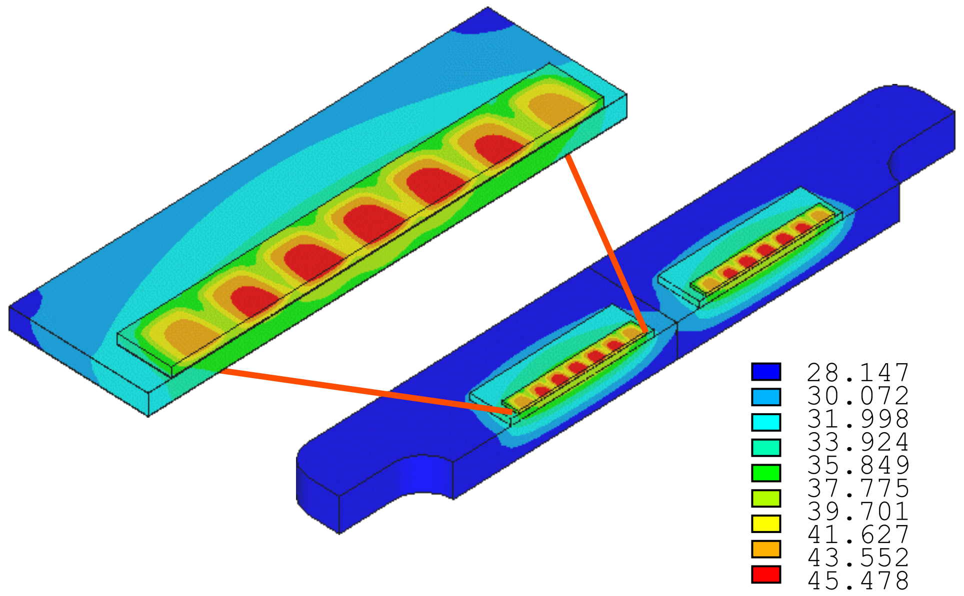

Rth reduced by 30% - delivering improved reliability and device linearity

Result: Significant temperature drop from junction to base using diamond heat spreader

CASE 3 - Continuous wave 160 W 2 GHz InAlN/GaN

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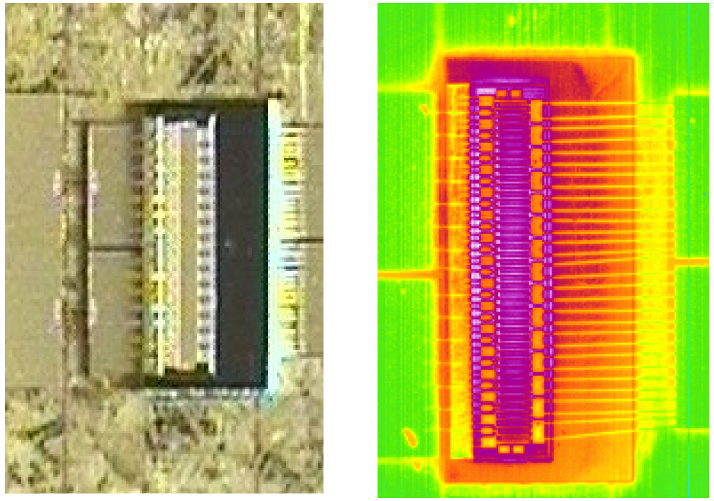
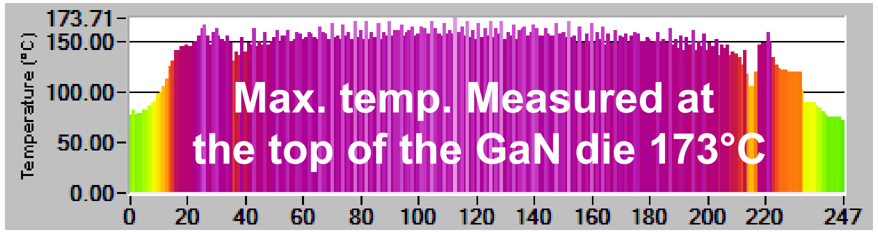
- SiC thinned with an E6 CVD diamond metallised heat spreader
- 41°C reduction in device surface temperature

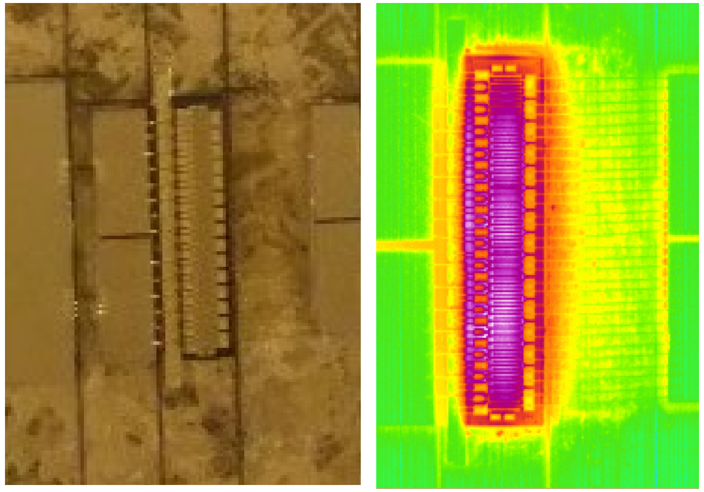
SiC with diamond heat spreader

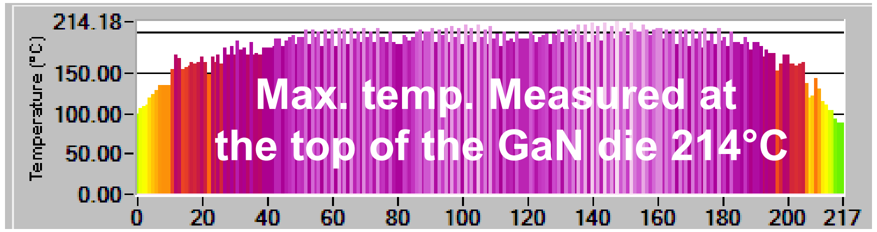




Assembly A
(SiC = 100 µm – Ti:Pt:Au: TM180: Ti:Pt:Au: Cu Sink)

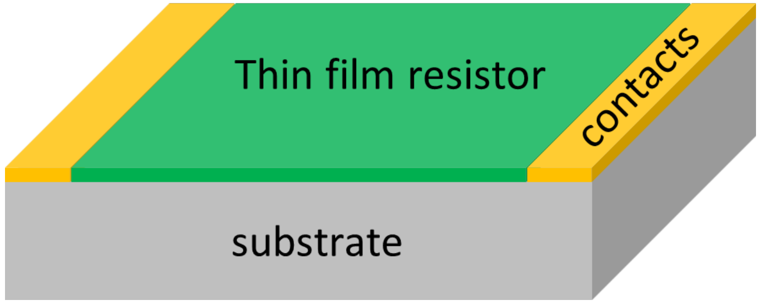
SiC with no diamond heat spreader



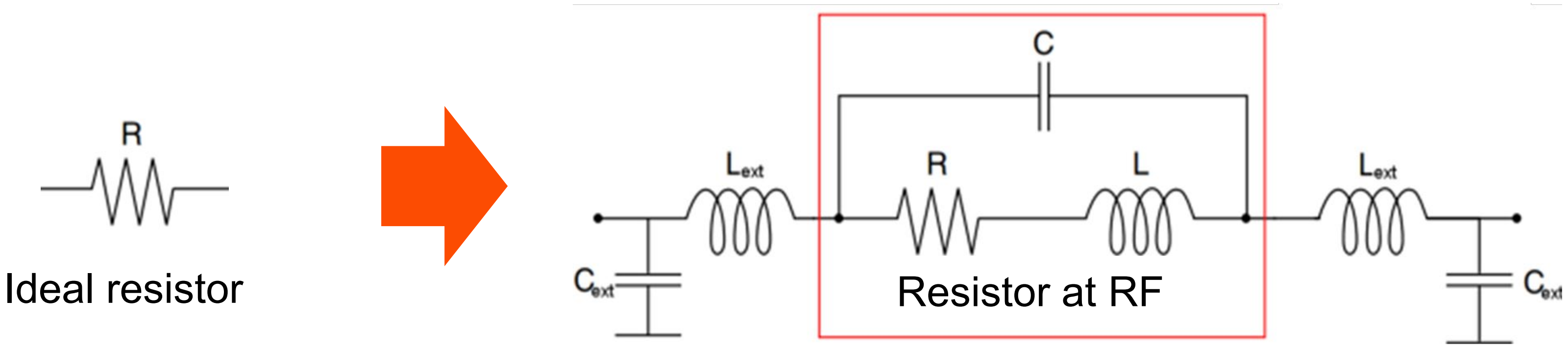


Assembly B
(SiC = 400 µm – no heat spreader)

CASE 4 - RF thin film resistors

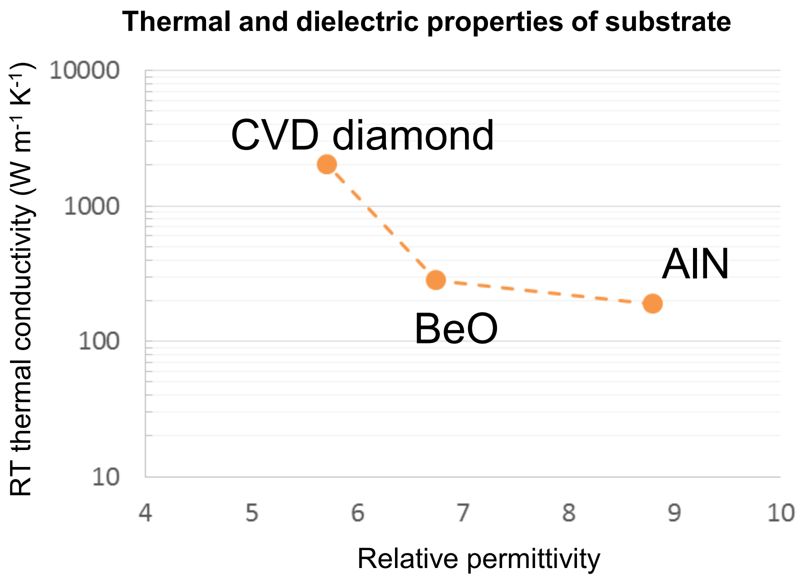


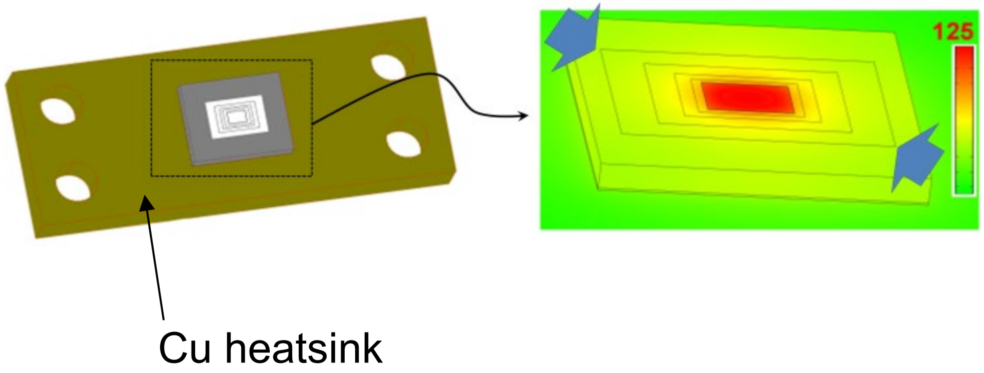
High power RF applications also require passive components able to handle high power densities (e.g. thin-film resistors)



- At microwave frequencies resistors deviate from ideal behaviour due to parasitic capacitance and inductance → leading to signal distortion
- Capacitive reactance usually dominates → minimise by reducing area of resistor
- High dissipated power leads to high temperature → minimise by increasing area of resistor

CASE 4 - RF resistors – substrate materials





- Low permittivity desirable to minimise parasitic capacitances
- High thermal conductivity desirable for power handling
- **Synthetic diamond has best combination of both**
- **Objective**: model performance of TiN thin film RF resistors on AlN, BeO and CVD diamond substrates
- What power and frequency can be achieved consistent with
  - Peak temperature < 125 °C
  - Low distortion (VSWR <1.25)

CASE 4 - RF resistors high power and frequency performance

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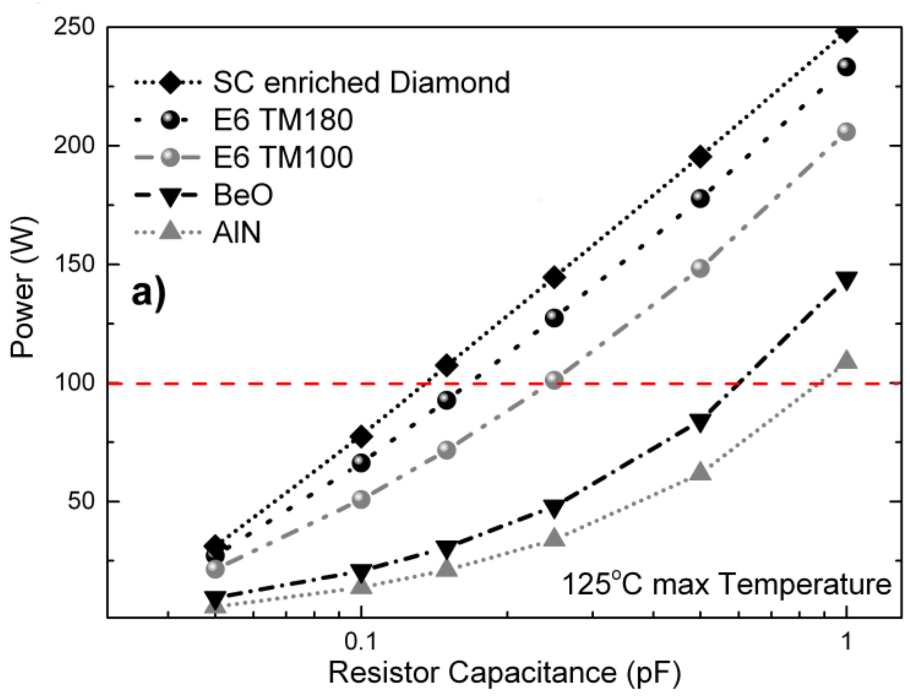
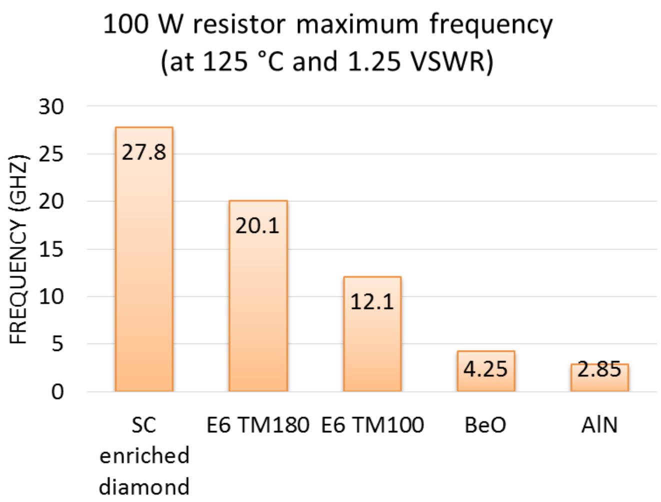


- Frequency of operation before parasitic effects become significant:
  - 2.9 GHz on AlN (S-band)
  - 4.3 GHz on BeO (C-band)
  - 12 – 27 GHz on synthetic diamond (Ku to K band)

- Results for 50 Ω thin film resistor
- For 100 W dissipated RF power, resistor parasitic capacitance is:
  - 0.9 pF on AlN substrate
  - 0.6 pF on BeO substrate
  - 0.1 - 0.2 pF on synthetic diamond substrate depending on thermal grade used



CASE 5 - CVD diamond handles a record 10 KW/cm^2 using microfluidics

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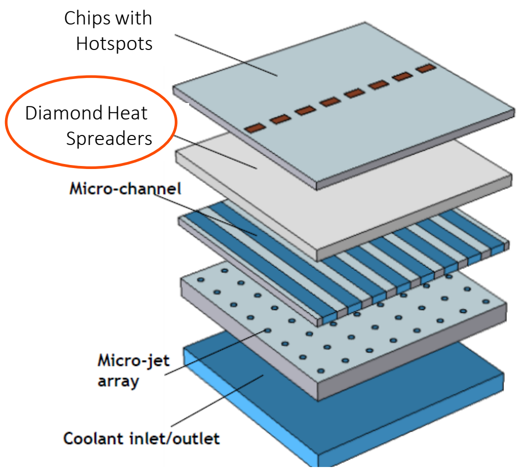
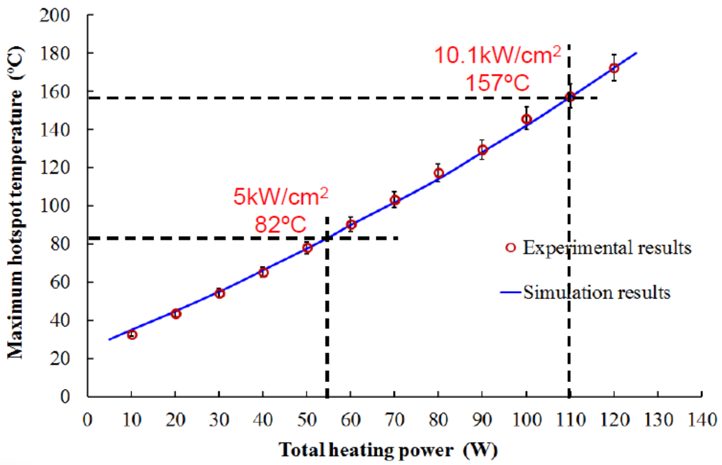
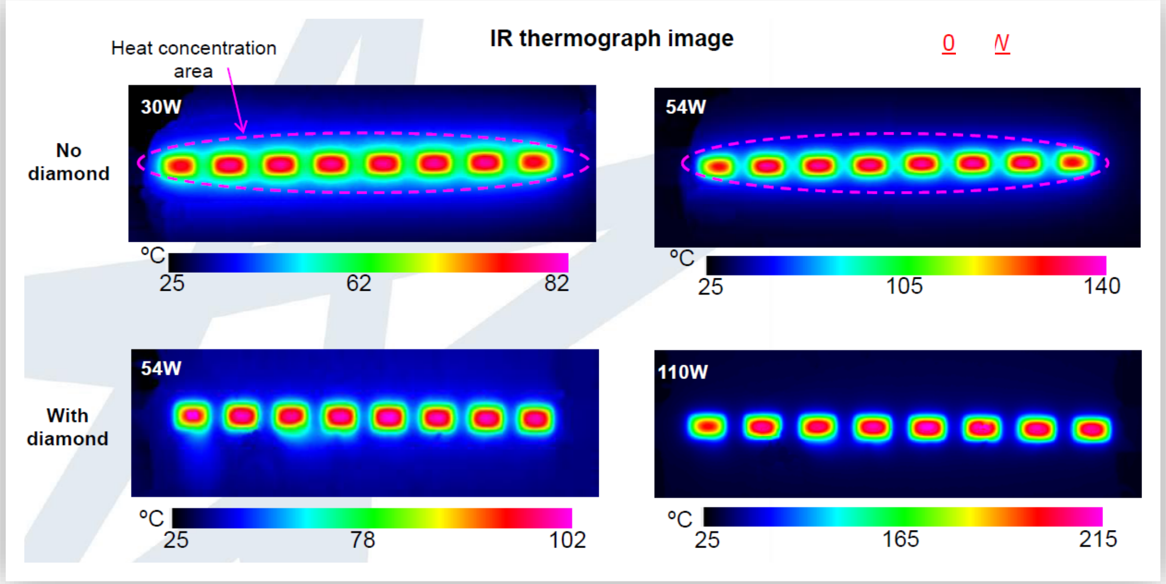




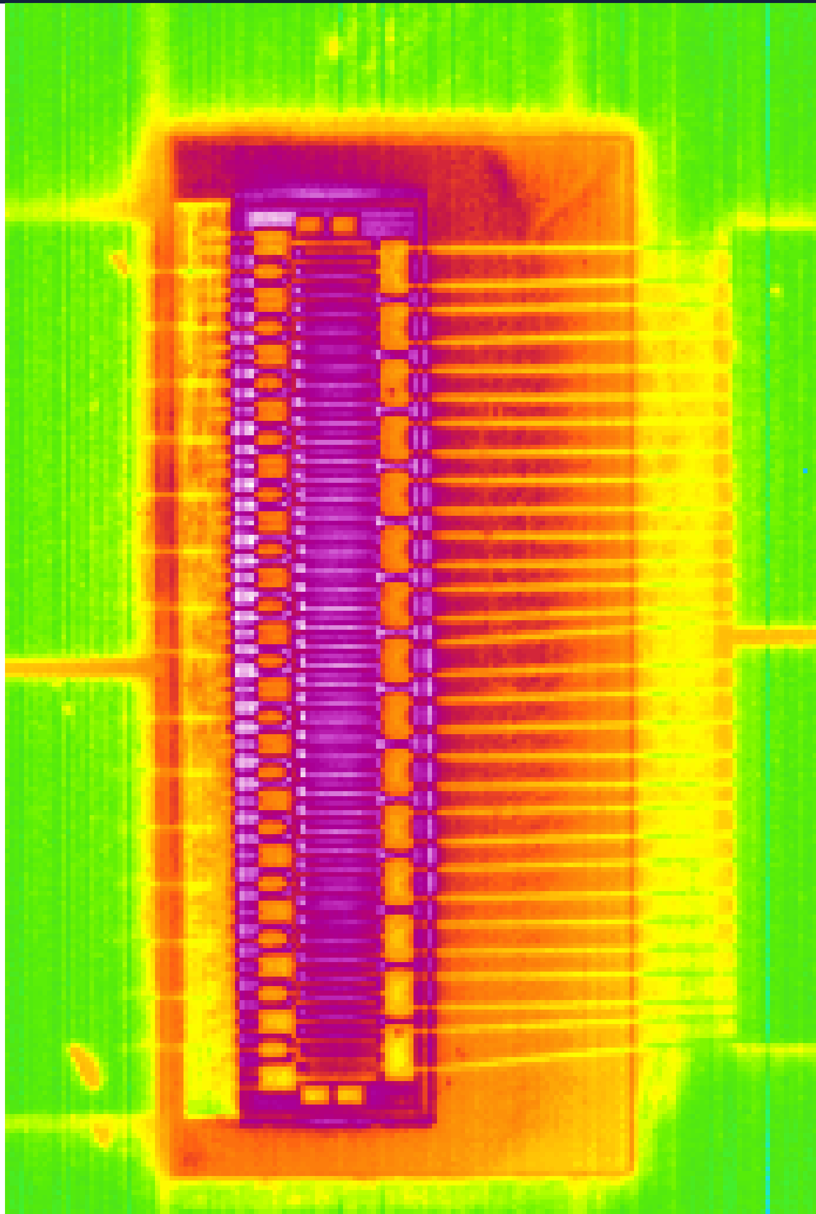


CVD diamond and microfluidics enables:

- 10 KW/cm^2 power density handling &
- 75 C Drop in max. hotspot

Summary

- Element Six's CVD diamond heat spreaders provide superior thermal management for high power RF applications
- Thermal conductivity can be engineered to suit your application
  - Need to consider the system as a whole for maximum benefits
- For active devices, CVD diamond heat spreaders enable:
  - Higher power operation for a given maximum operating temperature
  - Reduced peak temperatures (~25%) for a given power
- RF resistors using CVD diamond substrates can operate at higher frequencies and powers before parasitic effects lead to signal distortion
  - >100 W & > 10 GHz



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