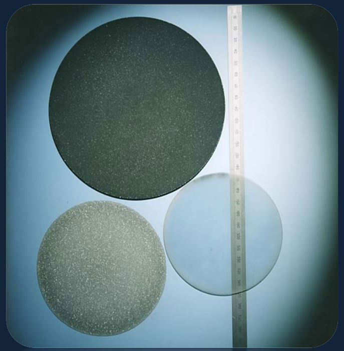
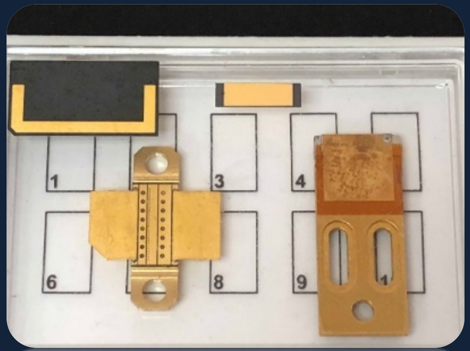
# Case studies

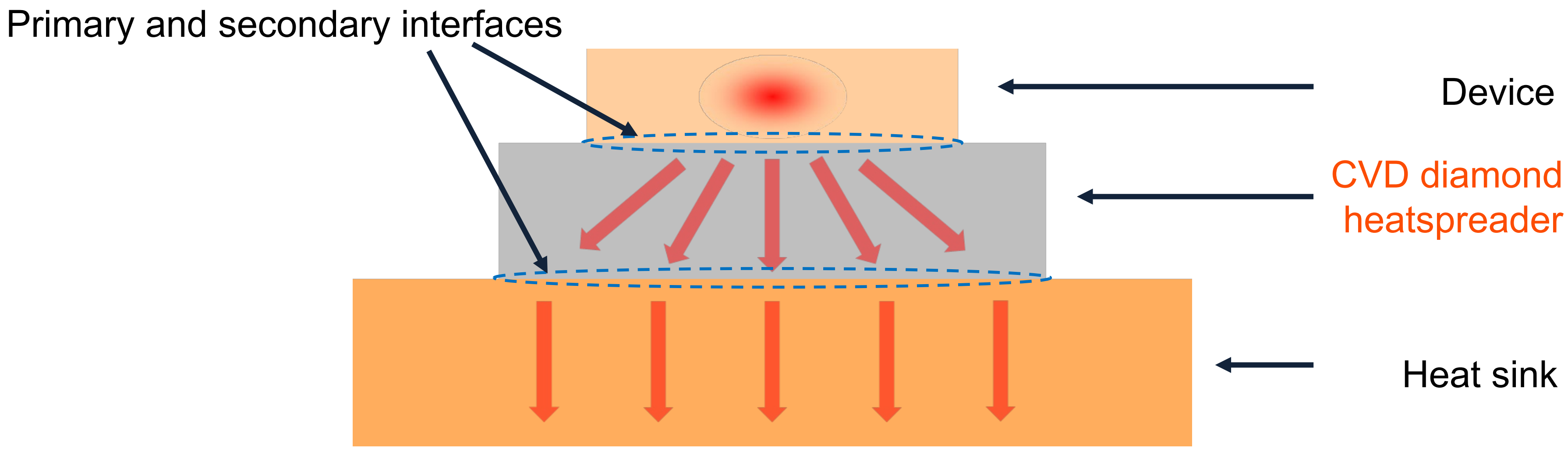
## Step change thermal management of RF devices using CVD diamond






July 2020

# Simple introduction – *a stack of thermal resistors*




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

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

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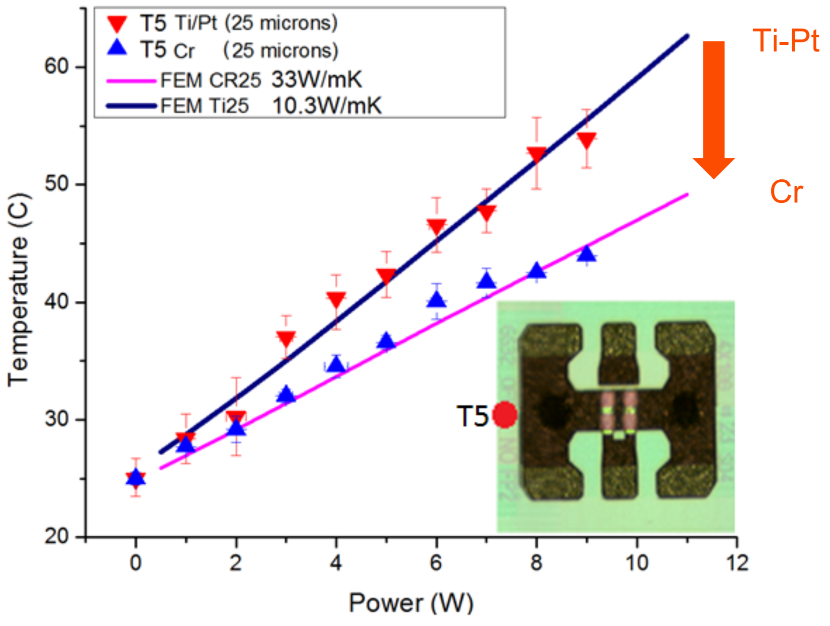
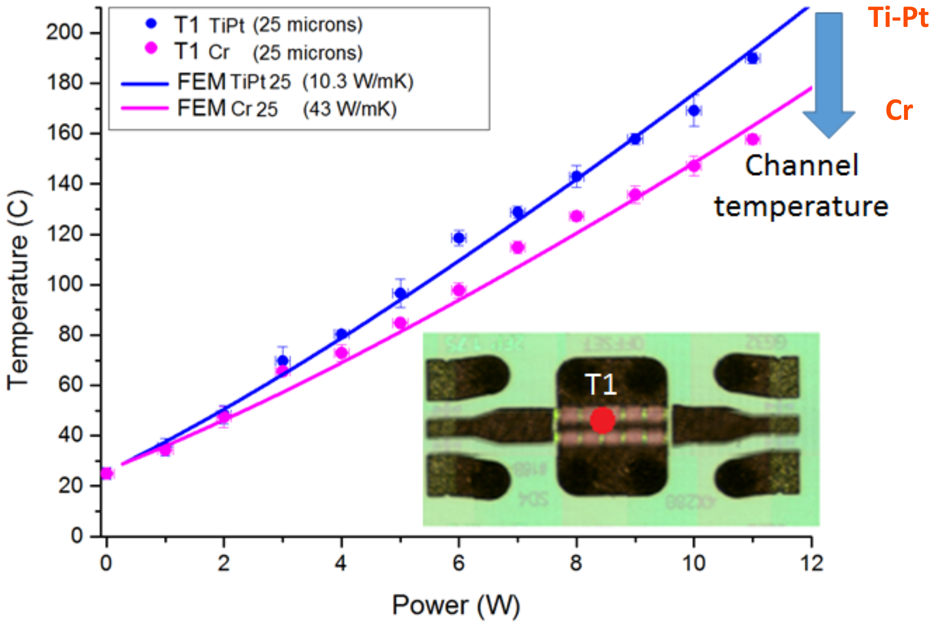
- A new metallization scheme (Cr) has improved the thermal conductivity of the die-diamond attach by 3-4X – compared to using Ti-Pt.
- With Cr, channel temperature drops 25% (for big devices e.g. high-power PAs), and 13% (for small devices) compared to using Ti-Pt.

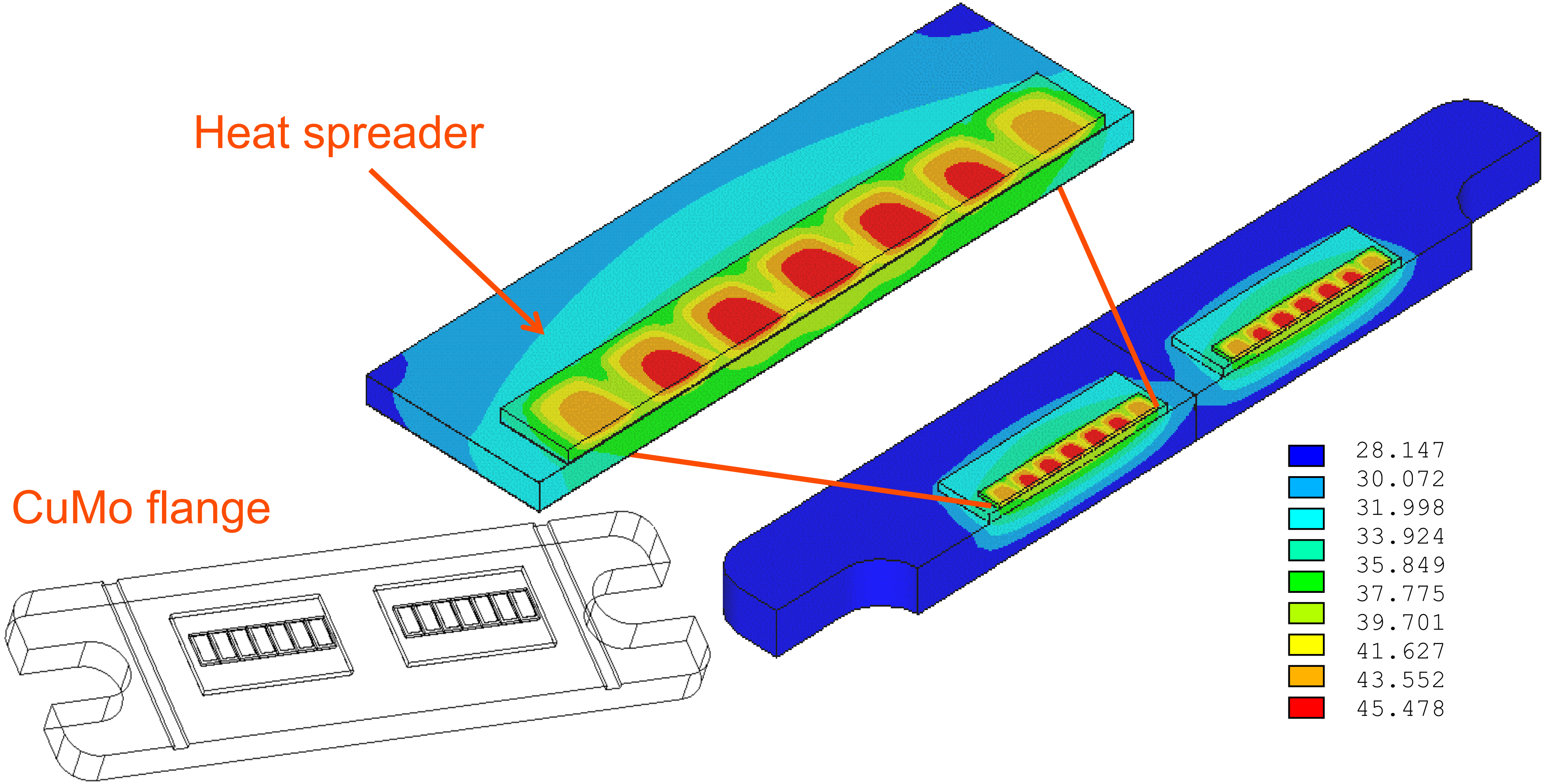
## Tj of "Big" Device (High Power Amplifier)




## Tj of "Small" Device



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




**Need to replace BeO for a combination of toxicity and thermal performance issues**

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

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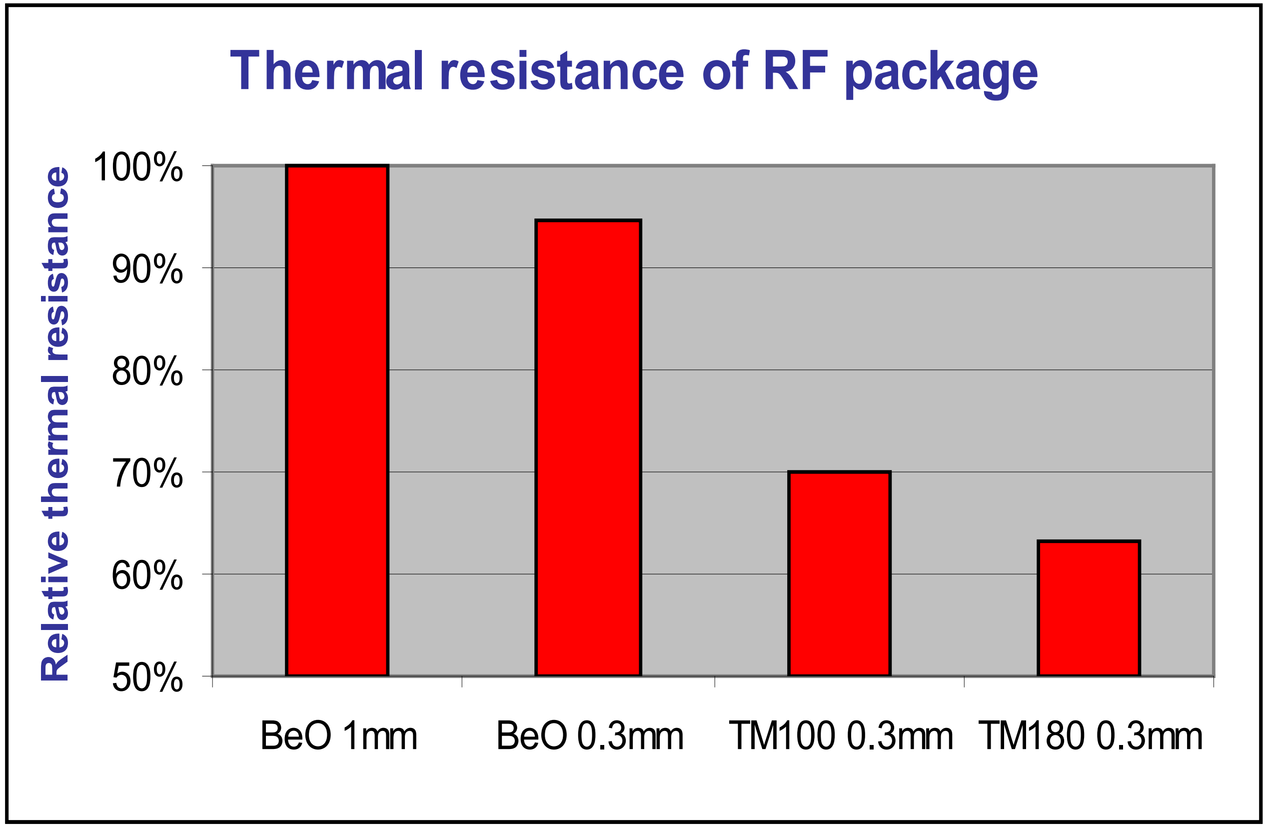
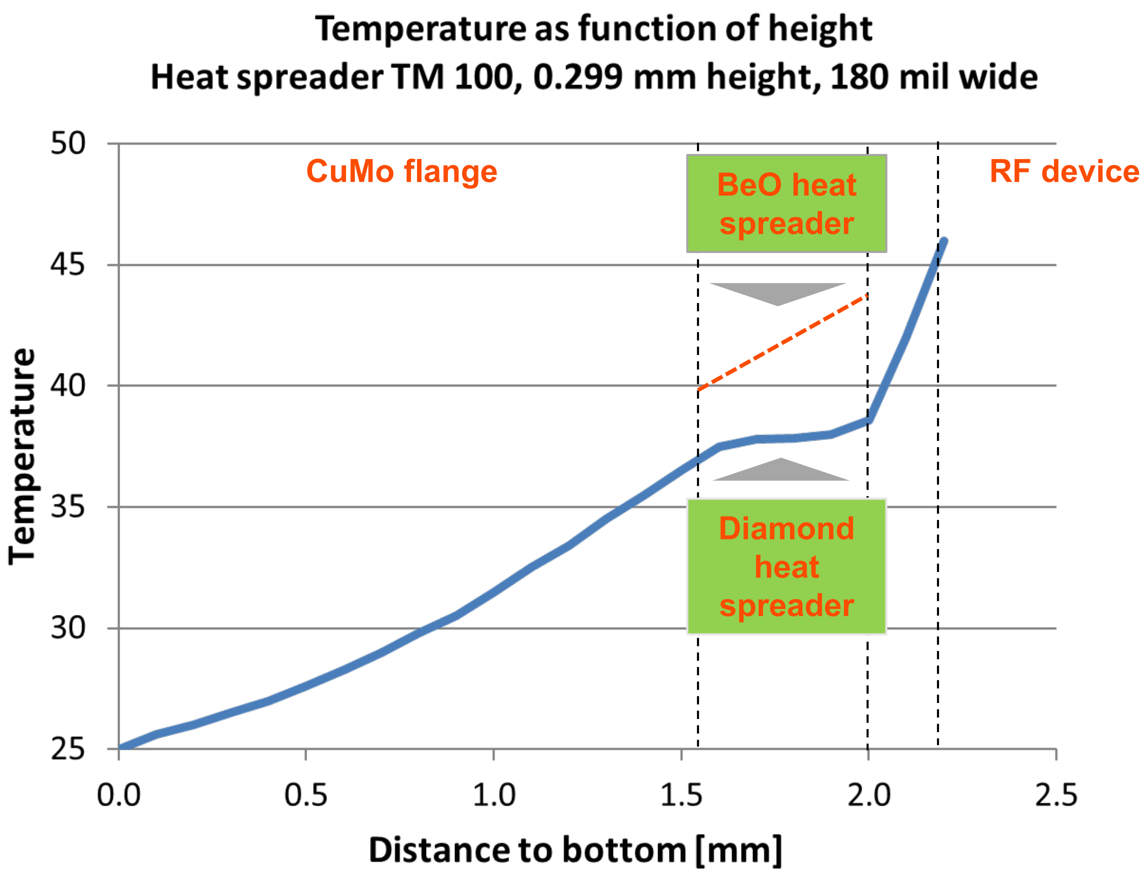
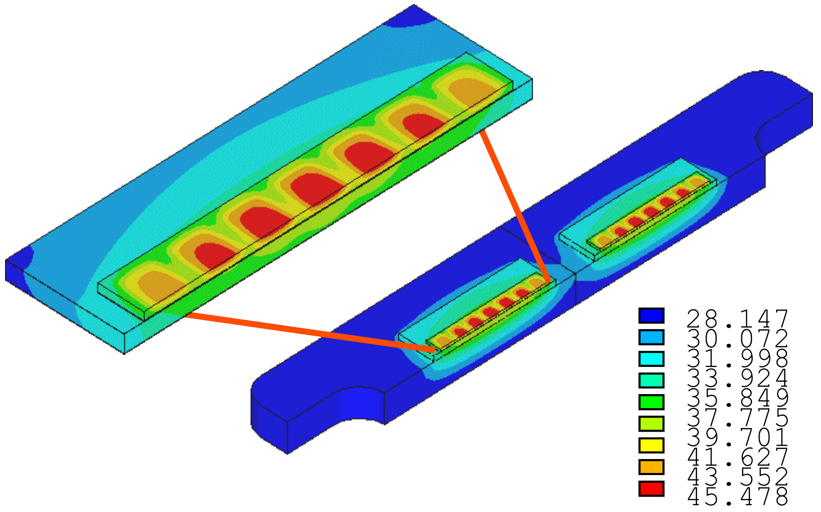



**Significant thermal resistance reduction in moving to diamond heat spreader**

# CASE 2 - CVD diamond for an RF package




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

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

# CASE 3 – Continuous wave 160W 2 GHz InAlN/GaN

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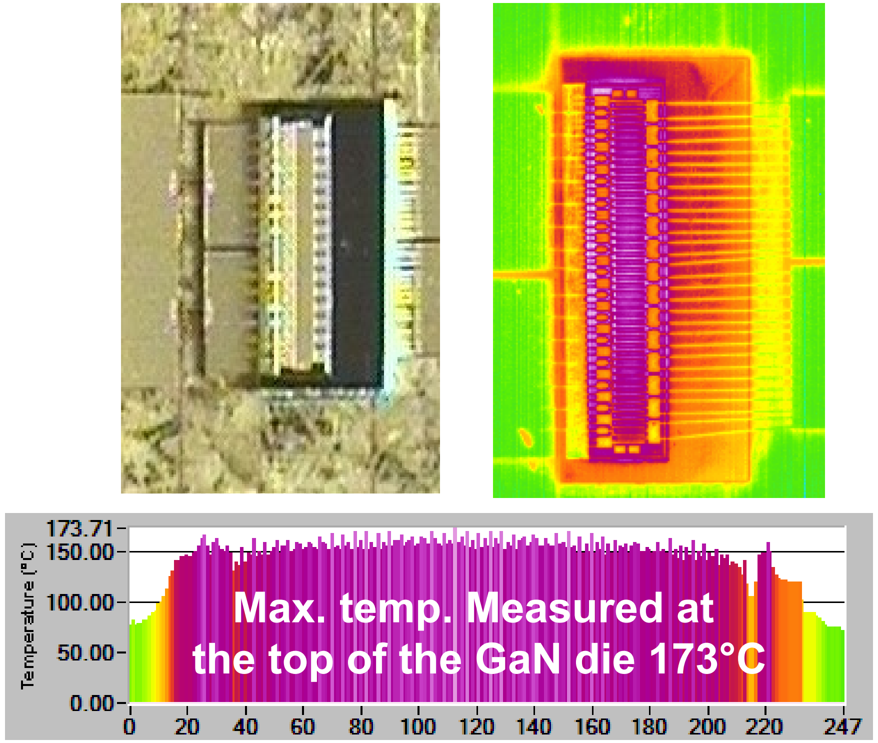
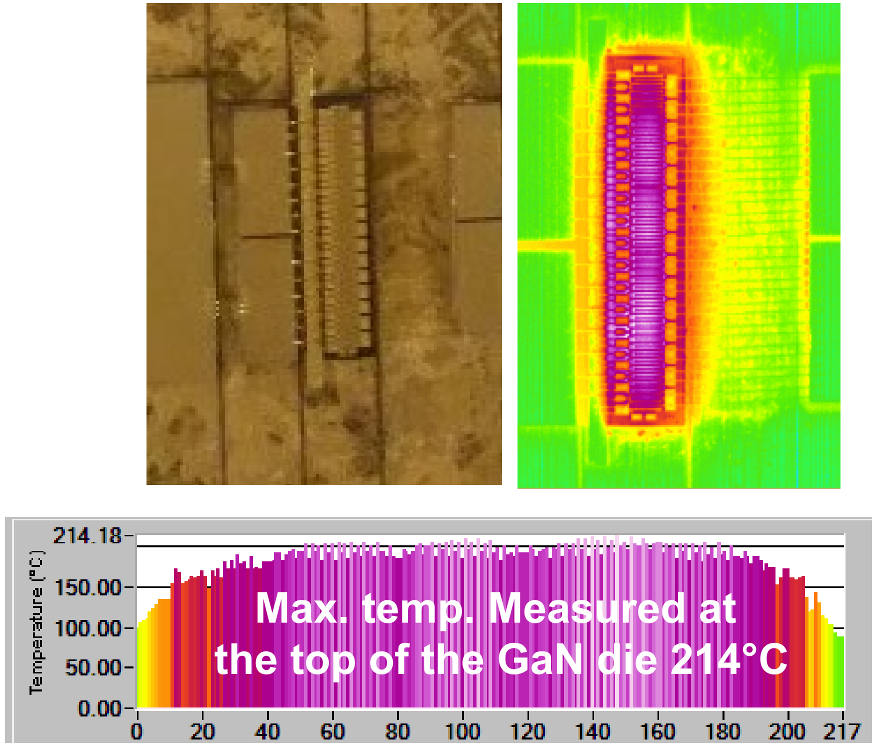
- SiC thinned with an E6 diamond metallized heat spreader
- 41°C reduction in device surface temperature

## SiC with diamond heat spreader



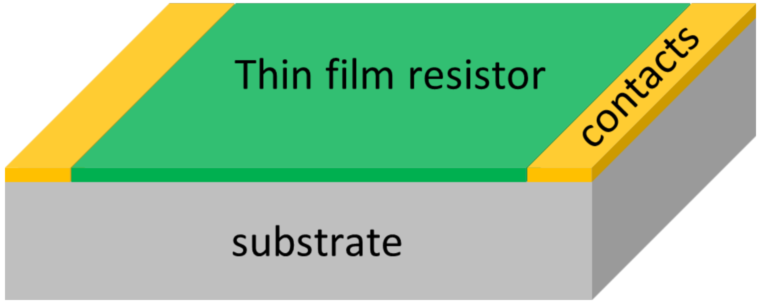

Assembly A
(SiC =100 µm – *Ti:Pt:Au:* TM180: Ti:Pt:Au: Cu Sink )

## SiC - no diamond heat spreader

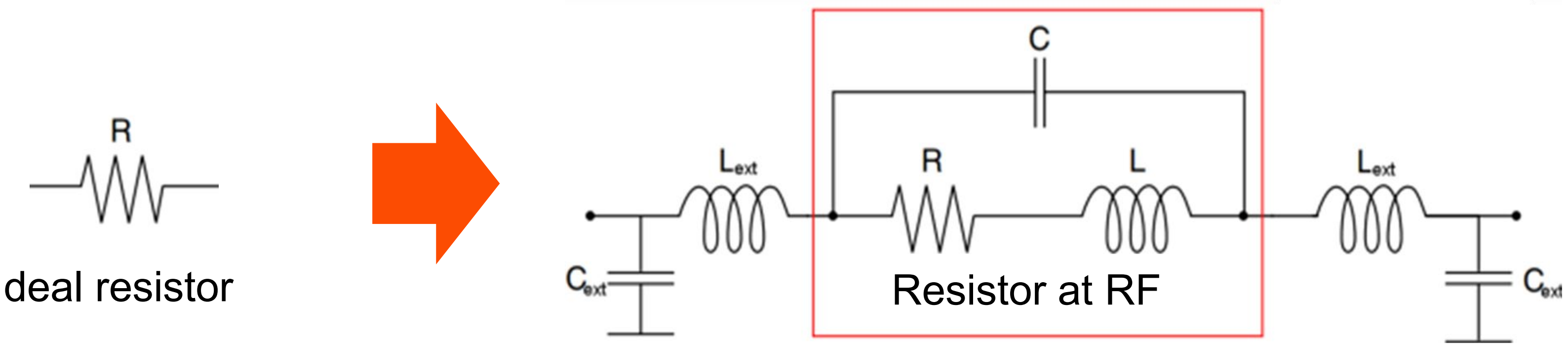



Assembly B
(SiC =400 µm – no heat spreader)

# CASE 4 - RF thin film resistors

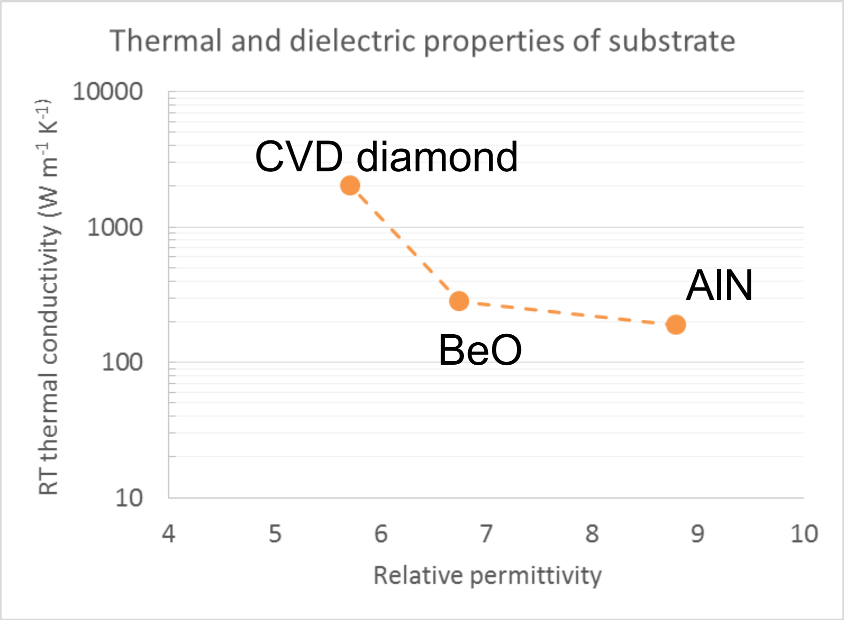


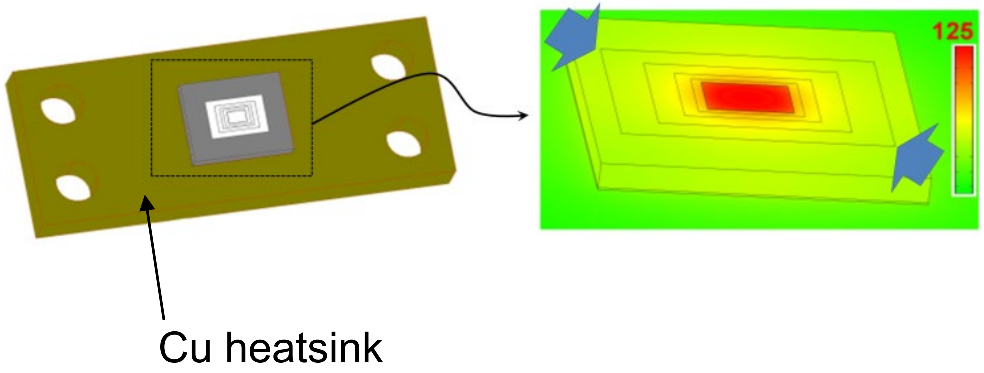

High power RF applications also require passive components able to handle high power densities e.g. thin-film resistors




- At microwave frequencies resistors deviate from ideal behaviour due to parasitic capacitance and inductance → 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

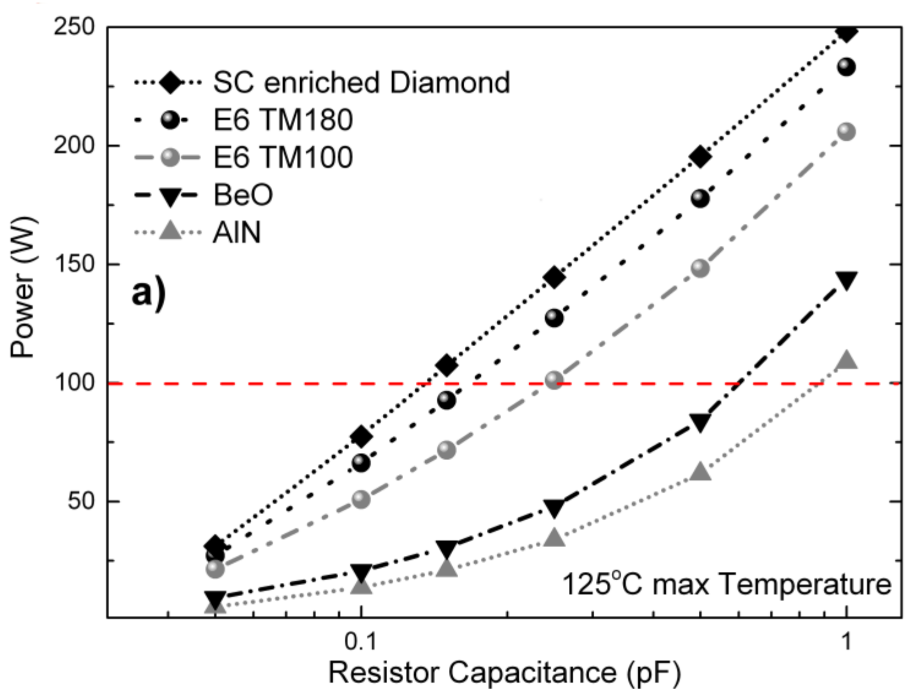
# CASE 4 - RF resistors – substrate materials



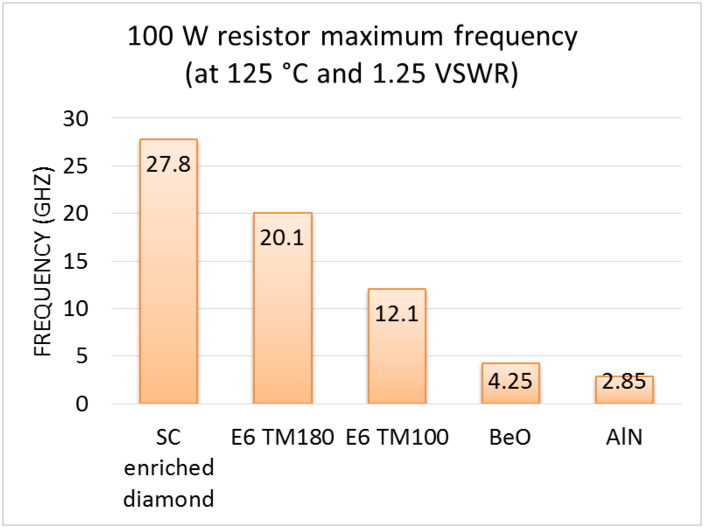

- Low permittivity desirable to minimise parasitic capacitances
- High thermal conductivity desirable for power handling
- Diamond has best combination of both
- **Objective**: model performance of TiN thin film RF resistors on AlN, BeO and CVD diamond substrates
- What power and frequency can be achieved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

# CASE 4 - RF resistors high power and frequency performance

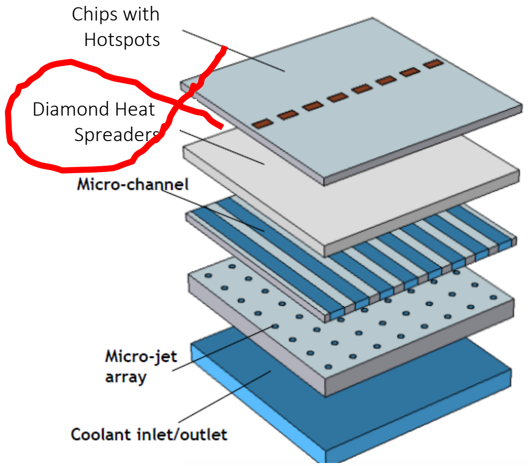


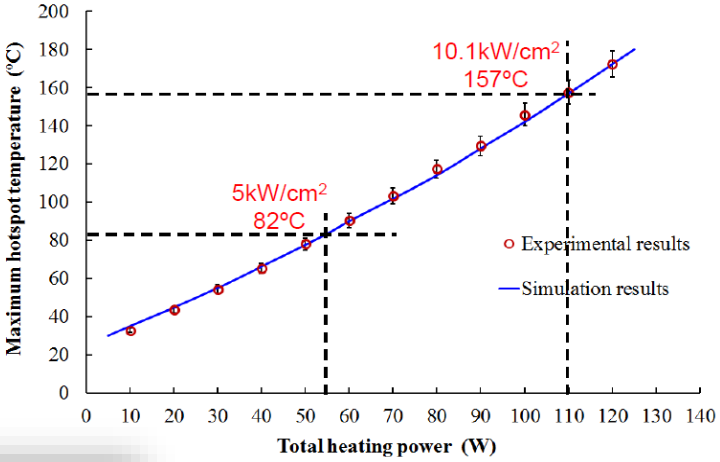

- Frequency of operation before parasitic effects become significant:
  - 2.9 GHz on AlN (S-band)
  - 4.3 GHz on BeO (C-band)
  - 12 – 27 GHz on diamond (Ku to K band)

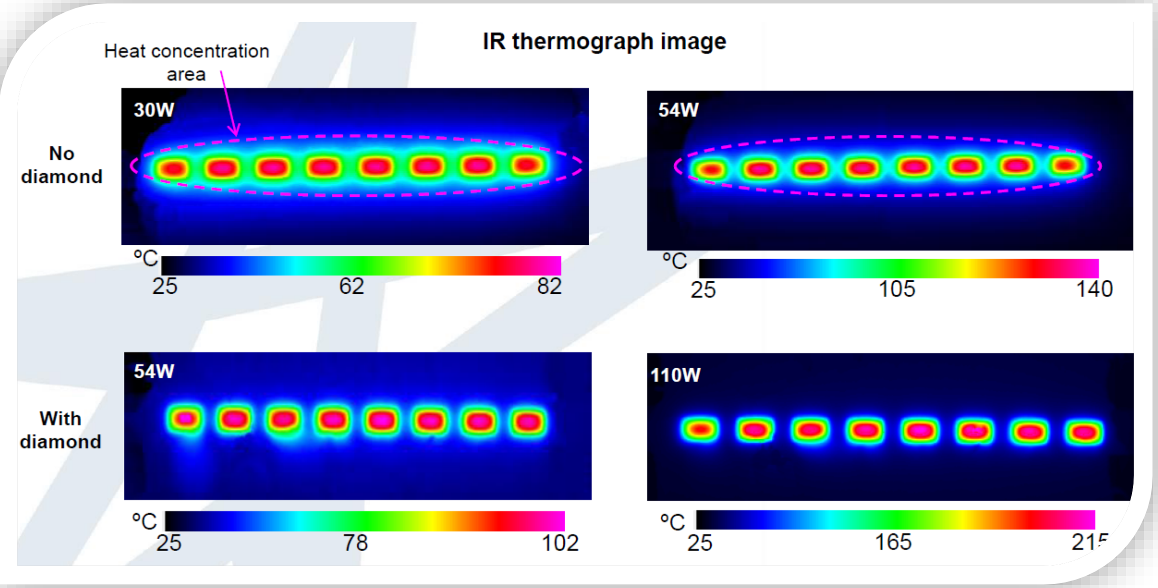
- Results for 50 Ω thin film resistor
- For 100 W dissipated RF power, resistor parasitic capacitance is
  - 0.9 pF on AlN substrate
  - 0.6 pF on BeO substrate
  - 0.1 - 0.2 pF on diamond substrate depending on thermal grade used



# CASE 5 - CVD diamond handles a record 10KW/cm² using microfluidics




## Diamond & microfluidics enables

- 10KW/cm² power density handling &
- 75C Drop in Max Hotspot

# Summary

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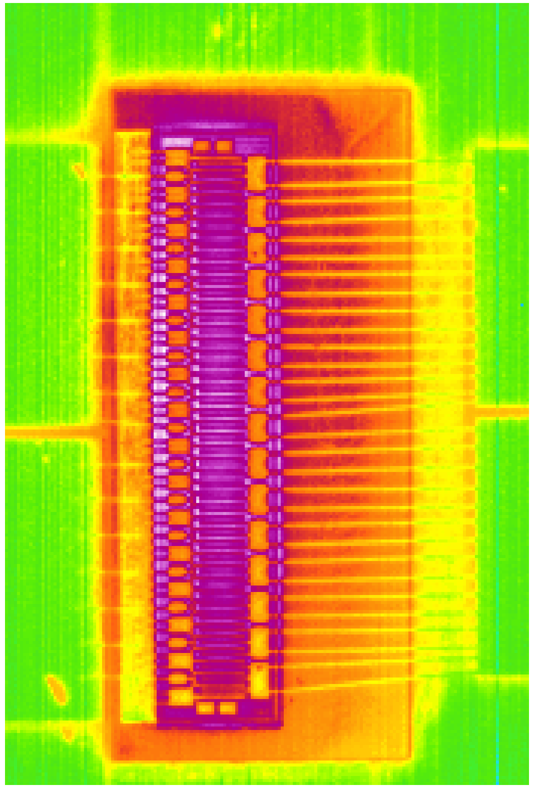
- CVD diamond heat spreaders provide superior thermal management for high power RF applications
- Thermal conductivity can be engineered to suite the application
  - Need to consider the system as a whole for maximum benefits
- For active devices CVD diamond heat spreaders enable:
  - Higher power operation 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
  - >100w & > 10 GHz



# Contact us to find out more

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