Case studies

Step change thermal management of RF devices using CVD diamond
**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%

- 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)**

<table>
<thead>
<tr>
<th>Temperature (°C)</th>
<th>Power (W)</th>
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<tbody>
<tr>
<td>20</td>
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<td>30</td>
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<td>40</td>
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<td>50</td>
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<td>60</td>
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**Tj of “Small” Device**

<table>
<thead>
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<td>120</td>
<td>10</td>
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Ti-Pt vs Cr comparison for different power levels.
Need to replace BeO for a combination of toxicity and thermal performance issues
CASE 2 - CVD diamond for an RF (GaAs) package

Significant thermal resistance reduction in moving to diamond heat spreader.
CASE 2 - CVD diamond for an RF package

Temperature as function of height
Heat spreader TM 100, 0.299 mm height, 180 mil wide

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

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

**SiC with diamond heat spreader**

Max. temp. Measured at the top of the GaN die 173°C

**SiC - no diamond heat spreader**

Max. temp. Measured at the top of the GaN die 214°C
CASE 4 - RF 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

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

- 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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