Excerpt – Direct Bonded Copper

Presented by

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Courtesy of Curamic Electronics
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A member of

Aavid™ Thermal Technologies, Inc.

for providing information and photos

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DCB Process

• Oxygen reduces the melting point of Cu from 1083°C to 1065°C (Eutectic melting temperature).
• Oxidation of copper foils or injection of oxygen during high temperature annealing (1065°C and 1080°C) forms thin layer of eutectic melt.
• Melt reacts with the Alumina by forming a very thin Copper-Aluminum-Spinel layer.
• Copper to copper is fused the same way.
• Copper-Aluminum-Nitride (AlN) DBC is possible. The AlN-Surface must be transformed to Alumina by high temperature oxidation.
Schematic diagram of the DBC (Direct Bonding Copper) Process.

1. **Copper**
2. **Ceramic**
3. **Copper Oxide**
4. **Eutectic Melt**

- **O₂** diffusion and cooling:
  - Copper
  - Ceramic

- **Temperature in °C**
  - 1080
  - 1070
  - 1060
  - 1050

- **O₂ Concentration in Atom-%**
  - 0
  - 0.4
  - 0.8
  - 1.2
  - 1.6

**Eutectic**

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Flow Chart of DBC Processing

- DBC Process
- Masking
- Etching
- Laser Scribing
- Final Cleaning
- Electroless Nickel
- Electroless Gold
- Separating mastercards by breaking
- Shipping to customer as single parts
- Shipping to customer as mastercards

Substrate blank
- copper surface
- Substrate Ni plated
- Substrate Ni + Au surface

Control

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Masking

- High precision screen printers for high volume
- Semiautomatic and fully automatic with pattern recognition
- Redundant equipment
- Photomasking for high density circuits
- Air conditioned clean rooms

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Etching

- Specially designed precision etchers for thick copper layers
- Automatic chemistry control
- Mask stripping integrated
- 3 separate high volume lines in operation
- Controlled by SPC

Courtesy of Curamic Electronics
Plating / Final Cleaning

• Fully automatic high volume plating line for electroless Ni + Au
• Controlled by SPC
• Final cleaning for Cu integrated
• Parallel backup lines
• Solderability and wire bond testing

Courtesy of Curamic Electronics
Laser Machining

• Fully automatic high precision CO$_2$ lasers with pattern recognition
• Designed for high volume throughput
• Scribing and drilling
• Multiple equipment
• Controlled by SPC
Features of DBC Substrates

- Low thermal coefficient of expansion despite relatively thick copper layers
  \( \text{TCE} = 7.2 - 7.4 \times 10^{-6} \text{ at } 0.3\text{mm} / 12\text{mil} \text{ copper} \)
- High current carrying capability with thick copper
  (Copper width 1mm / 40mil, height 0.3mm / 12mil, continuous flow 100amps = temp rise of 14 - 17°C)
- High peel strength of copper to Al2O3 \( \geq 60\text{N/cm} \);
  AlN \( \geq 45\text{N/cm} \) at 50mm/min peel speed
- High thermal conductivity
  (Al2O3 = 24W/mK; AlN = 170 W/mK)
- Low capacitance between front- and backside copper
  (Appr. 18pF/cm² for 0.63mm ceramic thickness)
Relative Heat Flux (W/sqm)

- Chips need Cooling
- Surface of Sun
- Power Semiconductor Chip
- Saturn V
- Engine
- (Case)
- Hot-Plate
- Logic Chips
- Light Bulb (100 W)
- Heat Loss from Human Body

Absolute temperature [K]

Source: Semikron

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Principal Design of IGBT Power Module

- Current contact
- Plastic casing
- Hard encapsulation
- Soft encapsulation
- IGBT / Diode
- Solder joint
- DBC substrate
- Cu baseplate
- Thermal grease
- Heat sink

Al thick wire bond

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Single Switch Module

4 Substrates, 4 IGBT‘s and 4 Diodes

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Power Module – Thermal Resistance

Thermal Resistance as a function of Substrate Thermal Conductivity

Chip area = 100mm²; ceramic thickness; 0.635mm; copper baseplate 3mm; power dissipation 100W; solder 0.070mm

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Thermal Mass

Junction temperature as function of the dynamic thermal resistance

Influence of copper thickness

Influence of Rth static

0,15 mm 0,3 mm 0,6 mm

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Courtesy of Curamic Electronics
Flexural Strength of DBC

as a function of copper thickness

![Graph showing flexural strength of DBC as a function of copper thickness. The graph includes lines for Alumina Standard and different DBC thicknesses.](image)

*Courtesy of Curamic Electronics*
Flexural Strength of HPS DBC

Compared with Blank HPS (optimized Alumina) Ceramic

![Graph showing comparison of Flexural Strength between DBC and Optimized Alumina.](image)

**Probability of Failure F [%]**

**Flexural Strength [MPa]**

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Dimple Design

Top view  Cross section

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Thermal Cycling Reliability

Standard Alumina DBC with and w/o Dimples

Probability of Chonchoidal Fracture F [%]

Number of Temperature Cycles

- Standard DBC
- Dimples DBC

Courtesy of Curamic Electronics
Average Life N0 – (Weibull)

*\(d_{\text{ceramic}}\) = 25 mil, \(d_{\text{Cu}}\) = 12 mil  
\(-55^\circ\text{C} / 150^\circ\text{C} / 15\text{ min.}\)

\(d_{\text{ceramic}}\) = 15 mil, \(d_{\text{Cu}}\) = 8 mil  
\(-55^\circ\text{C} / 150^\circ\text{C} / 15\text{ min.}\)

**without Dimples**

**with Dimples (Copper pattern design for thermal stress relief)**

**Courtesy of Curamic Electronics**
Special Substrates

- Active Metal Brazed (AMB)
- Refractory Metallization
- Substrates with vias
- Substrates with lead offs
- 3-Dimensional substrates
- DBC Packages
- Water cooled substrates
Via Technology

Both sides flat surface. Ceramic hole diameter min. 1.0mm R<100μΩ

One side flat surface. Ceramic hole diameter min. 1.0mm R<100μΩ

One side flat surface low cost. Ceramic hole diameter 2.5mm (0.3mm copper layer) R<100μΩ

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Vias in DBC Substrates

- High current front to back feed-through
  - 100 A current
  - 100 µOhm
- For backside ground-plane or shield
- Both hermetic
- Version 1 can be used as thermal path also

Courtesy of Curamic Electronics
Integral Terminals

• Terminals made of same copper sheet as circuit
• High electrical conductivity due to solid metal without interface resistance
• Very high reliability

Courtesy of Curamic Electronics
3-Dimensional DBC

- For very high density circuits
- Extremely reliable due to integral connectors
- Base for power
- Sidewalls for non-power components
- Assembled flat and bend up

Courtesy of Curamic Electronics
Package Types

Side Lead

Kovar Lid

Wirebond

Chip

Kovar Frame

Top Lead

Kovar Lid

Wirebond

Chip

Kovar Frame

1 Via

2 Direct Bonded Pin

Ceramic  Copper  1 Via  2 Direct Bonded Pin

Courtesy of Curamic Electronics
Package Types

- **Down Lead**
  - Kovar Lid
  - Wirebond
  - Chip
  - Kovar Frame

- **Glass to Metal Seals**
  - Kovar Lid
  - Wirebond
  - Chip
  - Glass
  - Kovar Pin

- **Surface Mount**
  - Kovar Lid
  - Wirebond
  - Chip
  - Kovar Frame

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Kovar Frame Brazed on DBC Substrate

Glass Sealed Feed-Through

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Fluid Cooled DBC

- Lowest thermal resistance of all available solutions for COB
- $R_{th}$ ranging from 0.08 to 0.02 K/W using Al2O3 or AlN
- Power dissipation up to 3 kW on 2” x 2”
- Extremely compact design
- Modular system assembly

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Liquid flow-through micro channels

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Micro Channels

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Micro Channel Water Cooled Module

Half bridge
6 IGBT
12 Diodes
62 mm Standard
module size
450 A
Cooling water
temperature up to 80°C
possible

Courtesy of Curamic Electronics
$R_{thja}$ as a Function of Water Flow

![Graph showing $R_{thja}$ as a function of water flow. The graph includes lines for AlN integration, Al2O3 integration, Al2O3 substrate, and AlN substrate. The x-axis represents water flow in l/min, and the y-axis represents $R_{thja}$ in mK/W.](image)

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Module comparison

Conventional v. Integrated water cooling

1 → Standard module on closed cooling system (calculation)
2 → Module with integrated cooling system (measurement: soldered Al₂O₃ ceramics)
3 → Module with integrated AlN substrate

About 60% reduction of $R_{thJA}$ (flowrate 2.5l/min.) 2 → 1

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