ALTIUMLIVE
PCB BASE MATERIAL PROPERTIES
AND DEVELOPMENT WHAT
DESIGNERS NEED TO KNOW

Alun Morgan
Technology Ambassador
Ventec International Group

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An Insulating Material, usually a composite comprising a resin and a reinforcement, with a conductor bonded to one or both sides.
PCB Base Material Resin Types

Epoxy
Phenolic
Polyimide
Bismaleimide Triazine (BT)
PPO
PTFE
Other Hydrocarbon
Blends and Multi-Phase systems

Standard

Low cost – Consumer Electronics
High Reliability – Military Aerospace
High Speed/Low Loss

Where it gets interesting.....
PCB Base Material Reinforcements

Glass – Woven
  - E Glass
  - D Glass
  - NE Glass

Glass – Non-woven

Paper

Composite – Paper + Woven Glass (CEM-1)

Composite – Woven & Non-woven Glass (CEM-3)

Aramid fibres

Standard

High Speed/Low Loss

Low cost – Consumer Electronics

Specialised
Resin/Reinforcement Selection Considerations

**Electrical**
- Dielectric Constant
- Dissipation Factor (loss)
- Dielectric Breakdown Strength
- Passive Intermodulation (PIM)
- Surface and Volume Resistivity
- Comparative Tracking Index

**Mechanical**
- Processability (Drilling, Punching, Laminating)
- Flexural and Tensile Strength
- Coefficient of Thermal Expansion (CTE)
- Thermal Conductivity
- Thermal cycling resistance
- Thermal Endurance
- Maximum Operating Temperature (MOT)
- Water Absorption
- Dimensional Stability
- Flammability
- Glass Transition Temperature
- Decomposition Temperature
- Foil Peel Strength

**Cost**

PCB Base Material Production Schematic

Raw Materials

Impregnation

Lay-Up

Pressing

Break Down

Finishing

Resin

Oven Tower

B-Stage

Press Plate

Glass Fabric

Resin

Copper Foil
Resins

Thermoplastic –
Polymers that can be softened and moulded on heating.

Thermoset –
Polymer systems that are cured on heating. Become permanently hard on exceeding a specific time and temperature.
From a permanent 3-D crosslinked network.
Temperature required to re-melt exceeds decomposition temperature.

Two Production Stages
1. Production of incompletely reacted pre-polymer – completed during resin blending and impregnation
2. Conversion to final cross-linked product – completed during pressing at high temperature
Liquid Epoxy Resin

$\text{Epichlorohydrin} + \text{DiPhenylPropane (BisPhenol A)} = \text{Resin} + \text{HCl}$
Brominated Epoxy Resin

2 x Diglycidylether of Bisphenol A (DGEBA) + Tetrabromo-bisphenol A (TBBA) → Bromine modified epoxy resin
Why use a Flame Retardant?

On average there are more than 4,500 fatalities annually in the EU-27 as a result of fires; this accounts for 2% of all fatal injuries.

Fires develop from inception through build-up until a stage where the total thermal radiation from the fire-plume, hot gases and hot compartment boundaries cause the radiative ignition of all exposed combustible surfaces within the compartment, so called “Flashover”

It is estimated that in a domestic dwelling fitted with working fire alarms on all levels where the occupants are asleep upstairs and a fire starts on the main level of the residence the occupants have about three minutes to escape if they are to have any chance of survival

Flame retardants are chemicals, which when added to materials during or after manufacture, inhibit or suppress the combustion process

They interfere with combustion at various stages of the process, e.g. during heating, decomposition, ignition or flame spread. They prevent the spread of fires or delay the time of flashover so that people can escape.
**Phosphorous Modified Epoxy Resin (Halogen Free)**

\[2 \times \text{Diglycidylether of Bisphenol A (DGEBA)} + \text{Organophosphorous compound} \rightarrow \text{Phosphorous modified epoxy resin}\]
The bromine breaks down to form a bromine radical which then reacts with the hydrocarbon to form HBr.

\[
R\text{-Br} \quad \longrightarrow \quad R\cdot + Br\cdot
\]
\[
R\text{-H} + Br\cdot \quad \longrightarrow \quad R\cdot + HBr
\]

The HBr removes the high energy H and OH radicals by reaction. The high energy radicals are replaced with low energy bromine radicals.

\[
HBr + OH\cdot \quad \longrightarrow \quad H_2O + Br\cdot
\]
\[
HBr + H\cdot \quad \longrightarrow \quad H_2 + Br\cdot
\]

The HBr consumed is regenerated by reaction with the hydrocarbon.

\[
R\text{-H} + Br\cdot \quad \longrightarrow \quad R\cdot + HBr
\]
Phosphorous Flame Retardant Mechanism

The phosphorus containing compound is converted by thermal decomposition to phosphoric acid. The phosphoric acid dehydrates the oxygen containing polymer and causes charring.

\[
\text{HO-PO-OH} + \text{-CH}_{2}\text{-O-} \xrightarrow{\text{DEHYDRATION}} \text{H}_3\text{PO}_4 + \text{C} - \text{H}_2\text{O}
\]
Epoxy Curing Chemistry

**Dicynandiamide**

**Phenolic Curing Agent**

**Solder Dip**
6 x 20 secs
@288°C
What is The Glass Transition Temperature (Tg)?

The glass transition temperature is the temperature at which higher molecular weight materials (polymers) undergo a phase change from a glassy brittle state to a viscous and rubbery state. This is associated with a significant increase in coefficient of thermal expansion (CTE).

Increasing relative degree of freedom.
Effect of Structure on Glass Transition Temperature (Tg)

Polyethylene
\[ \text{Tg} -110 \, ^\circ\text{C} \]
\[ \text{Tm} 115 \, ^\circ\text{C} \]

Polypropylene
\[ \text{Tg} -20 \, ^\circ\text{C} \]
\[ \text{Tm} 175 \, ^\circ\text{C} \]

Polystyrene
\[ \text{Tg} +100 \, ^\circ\text{C} \]
\[ \text{Tm} 240 \, ^\circ\text{C} \]
### Lead Free Soldering - Migration from “dicy” to Phenolic Curing

<table>
<thead>
<tr>
<th>Property</th>
<th>Units</th>
<th>Std Tg</th>
<th>High Tg 1</th>
<th>High Tg 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Curing Chemistry</td>
<td></td>
<td>Dicy</td>
<td>Dicy</td>
<td>Phenolic</td>
</tr>
<tr>
<td>Tg, ( DSC )</td>
<td>°C</td>
<td>140</td>
<td>175</td>
<td>175</td>
</tr>
<tr>
<td>Td, ( TGA - ASTM)</td>
<td>°C</td>
<td>310</td>
<td>300</td>
<td>350</td>
</tr>
<tr>
<td>T-260 ( TMA )</td>
<td>minutes</td>
<td>20</td>
<td>8</td>
<td>&gt; 60</td>
</tr>
<tr>
<td>T-288 ( TMA )</td>
<td>minutes</td>
<td>2</td>
<td>&lt; 1</td>
<td>&gt; 15</td>
</tr>
</tbody>
</table>
## Influence of Tg and Fillers on Thermal Expansion

<table>
<thead>
<tr>
<th>Property</th>
<th>Units</th>
<th>Std Tg</th>
<th>High Tg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Filler</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tg, ( DSC )</td>
<td>°C</td>
<td>140</td>
<td>175</td>
</tr>
<tr>
<td>CTE - z-axis ( 50-260 °C)</td>
<td>%</td>
<td>4.20</td>
<td>2.80</td>
</tr>
</tbody>
</table>

High z-axis expansion

Low z-axis expansion worst case: cracks and landlifting

[Image of high z-axis expansion]

[Image of low z-axis expansion]
<table>
<thead>
<tr>
<th>Property</th>
<th>Units</th>
<th>Std Tg</th>
<th>High Tg</th>
<th>High Tg</th>
<th>Next Generation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Curing Chemistry</td>
<td></td>
<td>Dicy</td>
<td>Dicy</td>
<td>Phenolic</td>
<td>Non dicy /non phenolic</td>
</tr>
<tr>
<td>Tg, (DSC)</td>
<td>°C</td>
<td>140</td>
<td>175</td>
<td>175</td>
<td>175</td>
</tr>
<tr>
<td>Td, (TGA - ASTM)</td>
<td>°C</td>
<td>310</td>
<td>300</td>
<td>350</td>
<td>400</td>
</tr>
<tr>
<td>T-260 (TMA)</td>
<td>minutes</td>
<td>20</td>
<td>8</td>
<td>&gt; 60</td>
<td>&gt; 60</td>
</tr>
<tr>
<td>T-288 (TMA)</td>
<td>minutes</td>
<td>2</td>
<td>&lt; 1</td>
<td>&gt; 15</td>
<td>&gt; 30</td>
</tr>
<tr>
<td>Dk, 2 Ghz</td>
<td>-</td>
<td>3.80</td>
<td>3.80</td>
<td>3.76</td>
<td>3.60</td>
</tr>
<tr>
<td>Dk, 5 Ghz</td>
<td>-</td>
<td>3.71</td>
<td>3.71</td>
<td>3.76</td>
<td>3.60</td>
</tr>
<tr>
<td>Dk, 10 Ghz</td>
<td>-</td>
<td>3.71</td>
<td>3.71</td>
<td>3.80</td>
<td>3.50</td>
</tr>
<tr>
<td>Df, 2 Ghz</td>
<td>-</td>
<td>0.020</td>
<td>0.020</td>
<td>0.025</td>
<td>0.003</td>
</tr>
<tr>
<td>Df, 5 Ghz</td>
<td>-</td>
<td>0.021</td>
<td>0.021</td>
<td>0.023</td>
<td>0.004</td>
</tr>
<tr>
<td>Df, 10 Ghz</td>
<td>-</td>
<td>0.021</td>
<td>0.021</td>
<td>0.023</td>
<td>0.005</td>
</tr>
</tbody>
</table>
Glass Fibre Production

Glass Yarn Production

- Raw Glass in Marble Form
- Melt Furnace
- Bushing
- Sizing
- Strand Forming
- Winding

Glass Yarn Common Types

<table>
<thead>
<tr>
<th>Yarn Designation</th>
<th>Filament Diameter</th>
<th>Filaments per Strand</th>
</tr>
</thead>
<tbody>
<tr>
<td>EC9 68 Tex</td>
<td>9 Microns</td>
<td>408</td>
</tr>
<tr>
<td>EC7 22 Tex</td>
<td>7 Microns</td>
<td>225</td>
</tr>
<tr>
<td>EC6 34 Tex</td>
<td>6 Microns</td>
<td>408</td>
</tr>
<tr>
<td>EC5 22 Tex</td>
<td>5 Microns</td>
<td>408</td>
</tr>
<tr>
<td>EC5 11 Tex</td>
<td>5 Microns</td>
<td>204</td>
</tr>
</tbody>
</table>

Figure 2: Glass Yarn Designation

E Glass (Electrical Grade)

- Continuous Filament
- Fibre Diameter (microns)
- Yarn Weight in Tex (grams per kilometre)
Glass Fibre Production

Plain Weave Fabric

Table 3: Traditional Woven Glass Fabric Styles

<table>
<thead>
<tr>
<th>Style</th>
<th>Glass Thickness (mm)</th>
<th>Weight (gsm)</th>
<th>Threads per cm</th>
<th>Yarn</th>
</tr>
</thead>
<tbody>
<tr>
<td>7628</td>
<td>0.17</td>
<td>203</td>
<td>17.3 x 12.2</td>
<td>EC9 68/EC9 68</td>
</tr>
<tr>
<td>2116</td>
<td>0.095</td>
<td>104</td>
<td>23.6 x 22.8</td>
<td>EC7 22/EC7 22</td>
</tr>
<tr>
<td>2125</td>
<td>0.09</td>
<td>87</td>
<td>15.7 x 15.4</td>
<td>EC7 22/EC9 34</td>
</tr>
<tr>
<td>2113</td>
<td>0.079</td>
<td>78</td>
<td>23.6 x 22.0</td>
<td>EC7 22/EC5 11</td>
</tr>
<tr>
<td>1080</td>
<td>0.05</td>
<td>47</td>
<td>23.6 x 18.5</td>
<td>EC5 11/EC5 11</td>
</tr>
<tr>
<td>106</td>
<td>0.033</td>
<td>24</td>
<td>22.0 x 22.0</td>
<td>EC5 5.5 /EC5 5.5</td>
</tr>
</tbody>
</table>
### Glass Fabric Images

#### Glass Style

<table>
<thead>
<tr>
<th>Glass Style</th>
<th>7628</th>
<th>2116</th>
<th>2113</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight (grams/sq.m)</td>
<td>203</td>
<td>104</td>
<td>78</td>
</tr>
<tr>
<td>Thread count</td>
<td>17.3 x 12.2</td>
<td>23.6 x 22.8</td>
<td>23.6 x 22.0</td>
</tr>
<tr>
<td>Yarn (warp/weft)</td>
<td>EC9 68/EC9 68</td>
<td>EC7 22/EC7 22</td>
<td>EC7 22/EC5 11</td>
</tr>
<tr>
<td>Glass thickness (mm)</td>
<td>0.17</td>
<td>0.095</td>
<td>0.079</td>
</tr>
<tr>
<td>Pressed thickness (mm)</td>
<td>0.18 - 0.22</td>
<td>0.110 - 0.125</td>
<td>0.085 - 0.10</td>
</tr>
</tbody>
</table>
## Glass Fabric Images

### Glass Fabric Images

<table>
<thead>
<tr>
<th>Glass Style</th>
<th>2125</th>
<th>1080</th>
<th>106</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight (grams/sq.m)</td>
<td>87</td>
<td>47</td>
<td>24</td>
</tr>
<tr>
<td>Thread count</td>
<td>15.7 x 15.4</td>
<td>23.6 x 18.5</td>
<td>22.0 x 22.0</td>
</tr>
<tr>
<td>Yarn (warp/weft)</td>
<td>EC7 22/EC9 34</td>
<td>EC5 11/EC5 11</td>
<td>EC5 5.5/EC5 5.5</td>
</tr>
<tr>
<td>Glass thickness (mm)</td>
<td>0.09</td>
<td>0.05</td>
<td>0.033</td>
</tr>
<tr>
<td>Pressed thickness (mm)</td>
<td>0.10 - 0.12</td>
<td>0.065 - 0.080</td>
<td>0.048 - 0.060</td>
</tr>
</tbody>
</table>
E-Glass has a Dielectric Constant of 6.6 @ 1MHz
Standard Epoxy has a Dielectric Constant of 3.5 @ 1MHz
FR4 laminate has a Dielectric Constant calculable from the volume proportions of these two components.
D.C. = 6.6xV(glass) + 3.5xV(resin)
Micro Dk Effect on Differential Pair

Glass fibre Dk = ~ 6.6
Resin Dk = ~ 3.5

Photomicrograph courtesy of Polar Instruments
## Glass fibre compositions

<table>
<thead>
<tr>
<th>Glass Compositions</th>
<th>E-glass</th>
<th>D-glass</th>
<th>NE-glass</th>
</tr>
</thead>
<tbody>
<tr>
<td>SiO₂</td>
<td>52~56%</td>
<td>72~76%</td>
<td>52~56%</td>
</tr>
<tr>
<td>CaO</td>
<td>16~25%</td>
<td>0%</td>
<td>0~10%</td>
</tr>
<tr>
<td>Al₂O₃</td>
<td>12~16%</td>
<td>0~5%</td>
<td>10~15%</td>
</tr>
<tr>
<td>B₂O₃</td>
<td>5~10%</td>
<td>20~25%</td>
<td>15~20%</td>
</tr>
<tr>
<td>MgO</td>
<td>0~5%</td>
<td>0%</td>
<td>0~5%</td>
</tr>
<tr>
<td>Na₂O·K₂O</td>
<td>0~1%</td>
<td>3~5%</td>
<td>0~1%</td>
</tr>
<tr>
<td>TiO₂</td>
<td>0%</td>
<td>0%</td>
<td>0.5~5%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Glass Properties</th>
<th>E glass</th>
<th>D glass</th>
<th>NE glass</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dk (1MHz)</td>
<td>6.6</td>
<td>4.1</td>
<td>4.4</td>
</tr>
<tr>
<td>Df (1MHz)</td>
<td>0.0012</td>
<td>0.0008</td>
<td>0.0006</td>
</tr>
<tr>
<td>Volume Resistivity (Ω)</td>
<td>over10¹⁵</td>
<td>over10¹⁵</td>
<td>over10¹⁵</td>
</tr>
<tr>
<td>Surface Resistivity (Ω)</td>
<td>over10¹⁵</td>
<td>over10¹⁵</td>
<td>over10¹⁵</td>
</tr>
</tbody>
</table>
## Square Weave Glass Fabrics

<table>
<thead>
<tr>
<th>Style</th>
<th>Glass Thickness (mm)</th>
<th>Weight (gsm)</th>
<th>Threads per cm</th>
<th>Yarn</th>
</tr>
</thead>
<tbody>
<tr>
<td>3313</td>
<td>0.084</td>
<td>81</td>
<td>23.6 x 24.4</td>
<td>EC6 16.5/EC6 16.5</td>
</tr>
<tr>
<td>1086</td>
<td>0.054</td>
<td>54</td>
<td>23.6 x 23.6</td>
<td>EC5 11/EC5 11</td>
</tr>
<tr>
<td>1078</td>
<td>0.043</td>
<td>48</td>
<td>21.3 x 21.3</td>
<td>EC5 11/EC5 11</td>
</tr>
<tr>
<td>1067</td>
<td>0.035</td>
<td>31</td>
<td>27.6 x 27.6</td>
<td>EC5 5.5/EC5 5.5</td>
</tr>
<tr>
<td>1035</td>
<td>0.028</td>
<td>30</td>
<td>26.0 x 26.8</td>
<td>EC5 5.5/EC5 5.5</td>
</tr>
</tbody>
</table>
## Square Weave Glass Fabrics

<table>
<thead>
<tr>
<th>Glass Style</th>
<th>106</th>
<th>1067</th>
<th>1080</th>
<th>1086</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight (grams/sq.m)</td>
<td>24</td>
<td>31</td>
<td>47</td>
<td>54</td>
</tr>
<tr>
<td>Thread count</td>
<td>22.0 x 22.0</td>
<td>27.6 x 27.6</td>
<td>23.6 x 18.5</td>
<td>23.6 x 23.6</td>
</tr>
<tr>
<td>Yarn (warp/weft)</td>
<td>EC5 5.5/EC5 5.5</td>
<td>EC5 5.5/EC5 5.5</td>
<td>EC5 11/EC5 11</td>
<td>EC5 11/EC5 11</td>
</tr>
<tr>
<td>Glass thickness (mm)</td>
<td>0.033</td>
<td>0.035</td>
<td>0.05</td>
<td>0.054</td>
</tr>
<tr>
<td>Pressed thickness (mm)</td>
<td>0.050 - 0.060</td>
<td>0.054 - 0.064</td>
<td>0.065 - 0.080</td>
<td>0.070 - 0.085</td>
</tr>
</tbody>
</table>
Square Weave Glass Signal Integrity
- Effect of Filament Distribution inside Glass Fabrics

April Article for Circuitree prepared by: Lee W. Ritchey, Speeding Edge 2/13/07

“By simply changing the style of glass used in the laminate, the problems of varying impedance and velocity have been substantially reduced.”
The Impedance Triangle

Lower Dk for Equivalent Df enables large trace size for ease of manufacture. Does not force a smaller trace geometry on manufacturing.
Differing Trace Width – Constant Reference Impedance

- Circuit Traces
- Reference Plane
- 5 Mil Above Reference plane

- 5 Mil
  - Dk 4.0
- 6 Mil
  - Dk 3.4
- 7 Mil
  - Dk 3.0
- 8 Mil
  - Dk 2.7
Differing Trace Height – Constant Reference Impedance

Circuit Traces

Reference Plane

6 Mil
Dk 2.7

6 Mil
Dk 3.0

6 Mil
Dk 3.4

6 Mil
Dk 4.0

Mil’s Above Reference plane

4
5
6
7
Dk (\(e_r\)) and Trace Width Relative to Characteristic Impedance (\(Z_0\))

\[ e_r \downarrow \rightarrow \text{Keep } Z_0 \rightarrow w \uparrow \]
Electrical Loss

All PCB materials exhibit both conduction and dielectric loss.

- The conduction losses are primarily resistive ($i^2r$) losses in the conduction layers and leakage of charge through the dielectric.

- The dielectric losses result from the varying field produced from the alternating electric field causing movement of the material’s molecular structure generating heat.
Dielectrics are materials which are poor conductors of electric current. They are insulators because they have few free electrons available to carry current.

However, when subjected to an electric field polarisation occurs whereby positive and negative charges are displaced relative to the electric field. This polarisation reduces the electric field in the dielectric thus causing part of the applied field to be lost.
Dipole Moment

The amount of polarisation that can occur in a dielectric material depends on the symmetry of the molecular structure and can be quantified by the “Dipole Moment”.

Within most molecular structures, although the overall charge is zero, the positive and negative charges do not overlap completely thus giving rise to a permanent Dipole Moment.

A good example of how this works is exhibited by water molecules in a microwave oven. As the field oscillates the molecules continuously rotate releasing kinetic energy as they collide with neighbouring molecules.
The effect of the dipole moment in a dielectric is quantified as “loss tangent” and describes the dielectric’s inherent dissipation of an applied electric field. The loss tangent derives from the tangent of the phase angle between the resistive and reactive components of a system of complex permittivity. The property is dimensionless and is often referred to by the following synonyms:

- Loss Factor
- Dissipation Factor
- Dielectric Loss
- Loss angle
- Tan δ

<table>
<thead>
<tr>
<th>Material</th>
<th>Loss factor (1GHz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air</td>
<td>~ 0</td>
</tr>
<tr>
<td>Alumina</td>
<td>0.0002</td>
</tr>
<tr>
<td>Water</td>
<td>0.06</td>
</tr>
<tr>
<td>E-glass</td>
<td>0.0012</td>
</tr>
<tr>
<td>NE-glass</td>
<td>0.0006</td>
</tr>
<tr>
<td>Standard FR4</td>
<td>0.015</td>
</tr>
<tr>
<td>Phenolic cured FR4</td>
<td>0.020</td>
</tr>
<tr>
<td>Ceramic filled low loss substrate</td>
<td>0.003</td>
</tr>
<tr>
<td>PTFE based PCB substrate</td>
<td>0.002</td>
</tr>
</tbody>
</table>
Copper Foil Production

Treatment of Copper Foils

- raw foil
- dendritic layer
- barrier layer

Diagram showing the process:
- Copper Foil Production
- Digester
- Reservoir-Tank
- Pump
- Heat-Exchanger
- Plating-Unit
- Oven
- Wind-Up
Copper Foil Production

Shiny Side

Electrodeposited foil

Matte Side
Copper Foil Production

Resist Side

Conventional foil

Bonding Side
Copper Foil Profile Specifications

- **Standard Foil**: 10 microns
- **Low Profile**: 5 - 9.9 microns
- **Very Low Profile**: < 5 microns

[Images of Copper Foil_profiles]
Skin Effect

The tendency of high frequency alternating current flow in a conductor to be confined to a layer in the conductor close to its outer surface.

At low frequencies the current distribution across the conductor is uniform, at higher frequencies the depth to which the flow can penetrate ($D_s$) is reduced.

\[ \delta = \sqrt{\frac{2}{\omega \mu \sigma}} \]

$\delta$ = skin depth (m)
$\mu$ = permeability ($4\pi \times 10^{-7}$ H/m)
$\pi$ = pi
$\rho$ = resistivity ($\Omega \cdot$m)
$\omega$ = radian frequency = $2\pi f$ (Hz)
$\sigma$ = conductivity (mho/m),

<table>
<thead>
<tr>
<th>Frequency</th>
<th>Skin Depth Copper</th>
</tr>
</thead>
<tbody>
<tr>
<td>50 Hz</td>
<td>9.3 mm</td>
</tr>
<tr>
<td>10 MHz</td>
<td>21 µm</td>
</tr>
<tr>
<td>100 MHz</td>
<td>6.6 µm</td>
</tr>
<tr>
<td>1 GHz</td>
<td>2.1 µm</td>
</tr>
<tr>
<td>10 GHz</td>
<td>0.66 µm</td>
</tr>
</tbody>
</table>
Skin Effect

**Resist side**

- **Standard foil**

- **Bonding side**

<table>
<thead>
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<th>Skin Depth</th>
</tr>
</thead>
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<tr>
<td>10 MHz</td>
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<th>Frequency</th>
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<td>100 MHz</td>
<td>6.6 µm</td>
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</tbody>
</table>

The current is able to tunnel below the surface profile and through the bulk of the conductor.

The current is forced to follow every peak and trough of the surface profile increasing path length and resistance.
Insulated Metal Substrates (IMS)

Why use Thermally Conductive PCBs?

• Keep heat generating components (LEDs / Embedded Components) cooler – increased component / product life
• Reduce system costs – reduction in size of or elimination of cooling fans / heatsinks (miniaturisation / HDI / Embedded)
• Ease of manufacture – conventional PCBs
• Use of standard assembly equipment
• FR4 ~ 0.25W/mK
• IMS - Glass Reinforced 1 - 3W/mK
• IMS non-reinforced, Bendable, 3 - 8W/mK and beyond
LED’s have a **higher efficiency** than incandescent lamps, however, almost \( \frac{3}{4} \) of their electrical power input is turned into heat.

As LED’s are components, it is essential to manage the heat in order to warranty the life and the quality of the light emitted by the LED.
## Thermal Conductivity

### Material Thermal Conductivity W/(m.K)

<table>
<thead>
<tr>
<th>Material</th>
<th>Thermal Conductivity W/(m.K)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acrylic</td>
<td>0.2</td>
</tr>
<tr>
<td>Air</td>
<td>0.024</td>
</tr>
<tr>
<td>Aluminium</td>
<td>250</td>
</tr>
<tr>
<td>Copper</td>
<td>400</td>
</tr>
<tr>
<td>Epoxy</td>
<td>0.35</td>
</tr>
<tr>
<td>Glass</td>
<td>1.05</td>
</tr>
<tr>
<td>PTFE</td>
<td>0.25</td>
</tr>
<tr>
<td>Silicon</td>
<td>149</td>
</tr>
<tr>
<td>Tin</td>
<td>67</td>
</tr>
<tr>
<td>Water</td>
<td>0.58</td>
</tr>
</tbody>
</table>

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**Graph:**

- **X-axis:** Board side dimension (mm)
- **Y-axis:** Temp increase from ambient (°C)
- **Legend:**
  - Red: Surface
  - Blue: Embedded

**Chart data source:** Microelectronics International, Vol 17 issue 2, Stubbs, Pulko et al.

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[www.ventec laminates.com](http://www.ventec laminates.com)
High Emissivity Solutions

- Getting rid of the large and heavy radiator
- Getting rid of the TIM
- Less weight
- Better design capability
- Lower total cost

The base plate of the IMS is used as a radiator, the back is surface treated to spread the heat within the entire IMS, thus increasing Emissivity
Material Roadmap: Thermal Management Materials

VT-4B1
1.0 W/m*K
IMS, Non-Glass, Bendable

VT-4A2
2.2 W/m*K
IMS, Glass Reinforced

VT-5A2
2.2 W/m*K
Thermally conductive cores & prepregs for ML and hybrid build-ups

VT-4B3
3.0 W/m*K
IMS, Non-Glass

VT-4B7
7.0 W/m*K
IMS, Non-Glass

VT-4A2H
2.2 W/m*K

VT-4B5
4.2 W/m*K
IMS, Non-Glass

VT-4B9
in development
10 W/m*K

www.venteclaminates.com
Thermal Management (IMS): Product Positioning

- **Ultra Low Rth**
  - VT-489*: 10.0 W/m.K
  - Thermal Conductivity > 7 W/m.K
  - min Rth 0.0078 °C*m/W

- **Low Rth**
  - VT-48SSP: 4.2 W/m.K
  - Thermal Conductivity > 3 W/m.K
  - min Rth 0.015 °C*m/W
  - VT-485 / VT-485L: 4.2 W/m.K
  - min Rth 0.019 °C*m/W
  - VT-483: 3 W/m.K
  - min Rth 0.026 °C*m/W

- **Mid Rth**
  - VT-5A2: 3.4 W/m.K
  - Thermal Conductivity > 1.6 W/m.K
  - min Rth 0.054 °C*m/W
  - VT-6A2: 2.2 W/m.K
  - min Rth 0.056 °C*m/W
  - VT-4A1: 1.6 W/m.K
  - min Rth 0.074 °C*m/W

- **Std Rth**
  - VT-4B1: 1.0 W/m.K
  - Thermal Conductivity > 1 W/m.K
  - min Rth 0.078 °C*m/W

* In Development