High Temperature Cofired Ceramic (HTCC) Package
Design and Applications

Presented at iMAPS New England

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HTCC Hermetic Packages

HTCC Packages Serve the High Performance Electronics Marketplace by Providing Hermetic Enclosures (Packages) for the Purpose of Protecting Delicate Integrated Circuits from the Environment

This Includes Protection Against Moisture, Heat, Thermal Shock, Thermal Expansion, and Corrosive Elements that are all Managed by the Package

www.hccelectronicpackaging.com
HTCC Packages Perform to Mil-Std-883 Test Requirements

Requirement for Hermetic Packages:
Electrically insulated enclosure to protect semiconductor devices from harsh environments over a 10 year lifetime
Hermeticity Leak Rate Standard: $1 \times 10^{-8}$ Std cc/sec He

Today’s Package Requirements:
Hermeticity Leak Rate: $1 \times 10^{-13}$ Std cc/sec He
Device Types: Si, HgCdTe, InSb, GaAs, GaN, Lithium Niobate
Device Threats: Moisture, organic residues, chemically-reactive gases, temperature stability
Package Contaminants: Outgassing, Surface Desorption
Two Predominant Hermetic Package Technologies: HTCC and GTMS

Hermetic Packaging Technologies

- **High Temperature Cofired Ceramic (HTCC)**
  90% Aluminum Oxide Ceramic
  Tungsten Metallization
  MolyManganese Metallization
  Kovar Sealrings, Leads, Pins
  Design Miniaturization Advantage
  Mechanical Shock Advantage
  Weight Advantage

- **Glass-to-Metal Seal (GTMS)**
  Kovar Housing
  Corning 7052 Glass Seals
  Lower Cost Advantage
HTCC Lead Terminal Density Advantage

- **HTCC Lead Terminal Density - Higher**
  
  Fine Pitch: 0.025 inch, Centerline
  Use of HTCC Package Design can double the number of output terminals as compared with GTMS

- **GTMS Lead Terminal Density - Lower**
  
  Minimum Pitch: 0.040 inch, Centerline
  (Double stacking of lead terminals is not competitive with HTCC)
HTCC DESIGN ADVANTAGE
Multilayer Structure Similar to Printed Wiring Board (PWB)

- High Routing Density
- Solid Metal Planes
  - Power / Ground
  - Controlled Impedance
  - Cross-talk Shield
  - Differential Signal Pairs
- Wirebondable Pads
- Kovar Sealrings
  - Parallel Seam Sealable
  - Laser Weldable
- Brazed-On Terminals
  - Pins
  - Leads
- Solder Pads
HTCC DESIGN ADVANTAGES
Multilayer Structure

- HTCC packages are characterized by layers of ceramic tape ranging from 0.004 to 0.010 inch thickness laminated together.

- These Layers have metallized circuit patterns in the “X – Y” plane. Conductive Vias pierce the layers in the “Z” Axis forming electrical interconnects between the layers.
CAVITY PACKAGE DESIGN
Typical Cross Section View

Kovar Sealframe

A1

Metallized for Braze Attach

A4

Metallized for Wire Bond

B1

Vias On Each Layer

B7

Metallized for Via Column Connection

C1

C4

Metallized for Braze Attach

Kovar Lead or Pin

CERAMIC LAYER STRUCTURE
HTCC DESIGN ADVANTAGES
“Custom Engineered Solutions”

- HTCC PROVIDES HIGHEST INPUT / OUTPUT TERMINAL DENSITY
  - 0.020 INCH LEAD PITCH IS 2X to 5X BETTER THAN GTMS
- HTCC OFFERS A WEIGHT REDUCTION ADVANTAGE
  - CERAMIC = 3.6 GRAMS PER CC
  - KOVAR = 8.3 GRAMS PER CC
- HTCC PROVIDES HERMETIC RELIABILITY IN HARSH ENVIRONMENTS
  - TEMPERATURE CYCLING: -65°C to +150°C; 1000 CYCLES
  - MECHANICAL SHOCK
  - VIBRATION
  - SALT ATMOSPHERE
  - 10 DAY MOISTURE EXPOSURE
- HTCC RELIABILITY EXCEEDS THAT OF GLASS-TO-METAL SEAL AND LOW TEMPERATURE COFIRE TECHNOLOGY
  - HTCC RESOLVES GTMS GLASS CRACKING ISSUES
  - HTCC HAS HIGHER STRENGTH THAN LTCC
  - <1 x 10^-13 HELIUM LEAK RATE: PROVEN 10 YEAR VACUUM LIFE
HTCC Design Possibilities

Package Types
Multilayer technology provides “3 Dimensional” design flexibility for high performance requirements

Ceramic to Metal
HTCC technology provides Design Freedom for Ceramic Feedthroughs in Metal Housings

Circular and Rectangular
The limitless design configurations provide the highest density hermetic packaging solutions available
HTCC “High Temperature Cofired Ceramic” Process Review
Process Review

- Tape Preparation
- Greenline Operations
- Firing Operations
- Post-Fire Operations
- Braze Integration
- Final Plating
- Final Inspection
- Ship

Diagram showing the sequential steps of a process with dotted arrows indicating flow.
Multilayer “Tape” Process
Via Punch & Via Fill Process

Greenline Operations
Ceramic Tape - “Green” (Unfired)
Flexible – Stretch Resistant
Punched and Filled Vias
Tungsten Paste
Screen Print Process

Greenline Operations
Screen Printed Circuit Pattern: Tungsten Ink
Lamination Process

- **Lamination Process**
  - Process Requires Heat and Pressure to Compact Multiple Tape Layers into a Monolithic Structure
  - Process Requires Forming Mold with Guidepins to Ensure Precision Stacking and “No Layer Dislocation or Shift”
Diamond Dice

Post-Fire Operations
Laser Machining

Post-Fire Operations
Molymanganese Screen Printing

Post-Fire Operations
HTCC Package Applications

Military/Defense -

Commercial Aerospace -
- SAT COM Systems, Aircraft Motion Sensors and Databus Communications, Programmable Radio Frequency Amplifiers, Signal Processing Subsystems, etc....

Industrial -
- DC-to-DC Power Converters, Integrated Circuits, Synchro to Digital Converters, Voltage Regulators, Motor Controls, Up/Down Converters

Medical -
- Imaging Equipment, Monitoring Equipment, Pacemakers, Defibrillators, Glucose Detection Systems, etc....

Optical -
- Electro Optical Tx and Rx modules, Laser Devices, Modulators, Clock Amplifiers, Attenuators, Mux/Demux, Optical Add Drop Modules, etc....
Circular Connectors / Feedthroughs / Headers
HTCC Feedthrough Products: Rectangular Feedthrough Designs
HTCC Optical Telecom Package:
Laser Packages - Dense wavelength division multiplexing (DWDM)

Design Features

- HTCC Ceramic Feedthroughs
- Laser Weldable Optical Port
- Selfoc “GRIN” Lens
- Sapphire Lens with AR Coating
- 50 Ohm SMA Connector
- 50 Ohm GPPO Connector
- Ceramic “RF” Launch
- Tungsten-Copper Base
HTCC Infrared Dewar Assembly
Infrared Thermal Imaging
Infrared Thermography

Airport Surveillance
Power Management Products:
HTCC Ceramic with Tungsten-Copper Electrodes
Ceramic Material, Shrinkage, and Flatness Control

<table>
<thead>
<tr>
<th>DESCRIPTION</th>
<th>Standard Process</th>
<th>Advanced Process</th>
<th>COMMENTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>CERAMIC TAPE</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Black Aluminum Oxide</td>
<td>92% Alumina</td>
<td>Premium Cost</td>
<td>Standard Material, No Premium Charge</td>
</tr>
<tr>
<td>White Aluminum Oxide</td>
<td>94% Alumina</td>
<td></td>
<td>Better High Frequency Performance, Higher Flexural Strength, Higher Sintering Temperature, Higher Cost</td>
</tr>
<tr>
<td>Layer Thickness</td>
<td>0.010 inch</td>
<td>0.004 inch</td>
<td>Tape Layers are Cast and Gauged in increments of 0.0005 inch.</td>
</tr>
<tr>
<td>Standard Minimum</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Length x Width Control</td>
<td>±1.0%</td>
<td>±0.5%</td>
<td>AMETEK Can Provide ±0.5% Thickness Control at Higher Cost</td>
</tr>
<tr>
<td>&quot;As-Fired&quot;</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Thickness Control</td>
<td>±10%</td>
<td>±5%</td>
<td>AMETEK Can Provide ±5% Thickness Control at a Higher Cost</td>
</tr>
<tr>
<td>&quot;As-Fired&quot;</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flatness Control</td>
<td>0.004 inch / inch</td>
<td>0.002 inch / inch</td>
<td>AMETEK Can Provide 0.002 inch / inch Flatness at a Higher Cost</td>
</tr>
<tr>
<td>&quot;As-Fired&quot;</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Tape Formulation: AMETEK Casts proprietary tape formulations "in house", starting with refined ceramic powder, binder, and solvents procured to AMETEK specifications.
# Ceramic Greensheet Design Selection

**COST FACTORS:** Part Size, Layer Thickness, Number of Layers

<table>
<thead>
<tr>
<th>Design Features</th>
<th>Standard Design</th>
<th>Advanced Design</th>
<th>COMMENTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Size Limitations</td>
<td>Standard Cost</td>
<td>Premium Cost</td>
<td>1.7 inch is a &quot;Best Fit&quot; for AMETEK's standard tooling patterns and provides the lowest manufacturing cost.</td>
</tr>
<tr>
<td>Package Length x Width</td>
<td>1.7 inches Length</td>
<td>Up to 4 inches Length</td>
<td>Flatness is a concern below 0.030 inch. Green Cutting Perpendicularity is limited to approx 0.2 inch max thickness. Diamond Dicing may be used for thicknesses up to 0.5 inch max.</td>
</tr>
<tr>
<td></td>
<td>1.7 inches Width (max)</td>
<td>4 inches Width (max)</td>
<td></td>
</tr>
<tr>
<td>Package Thickness</td>
<td>0.040 to 0.100 inch</td>
<td>0.100 to 0.500 inch</td>
<td>AMETEK has manufactured parts with up to 74 layers</td>
</tr>
<tr>
<td>Number of Layers</td>
<td>Up to 15</td>
<td>16 to 70</td>
<td></td>
</tr>
<tr>
<td>Layer Thickness (As Fired)</td>
<td>0.0100 inch standard</td>
<td>0.0075 inch</td>
<td>AMETEK Selects Each Layer Thickness in increments of 0.0005 inches to Meet Customer Requirement</td>
</tr>
<tr>
<td></td>
<td>0.0095</td>
<td>0.0070</td>
<td>Layer Thickness Greater Than 0.010 is Achieved by Combining Two or More Layers</td>
</tr>
<tr>
<td></td>
<td>0.0090</td>
<td>0.0065</td>
<td>Minimum: 0.004 inch Fired Thickness is Possible</td>
</tr>
<tr>
<td></td>
<td>0.0085</td>
<td>0.0060</td>
<td>AMETEK Can Provide ± 5% Thickness Control at a Slight Premium</td>
</tr>
<tr>
<td></td>
<td>0.0080</td>
<td>0.0055</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.0050</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.0045</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.0040 minimum</td>
<td></td>
</tr>
<tr>
<td>Layer Thickness</td>
<td>±10%</td>
<td>± 5 %</td>
<td></td>
</tr>
</tbody>
</table>
# Via Punching Design Rules

**VIA COST FACTORS:** Via Count, Via Size, Layer Aspect Ratio, Via Centerline Pitch

<table>
<thead>
<tr>
<th>DESCRIPTION</th>
<th>Standard Design</th>
<th>Advanced Design</th>
<th>COMMENTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>VIA DESIGN RULES</td>
<td>Standard Cost</td>
<td>Premium Cost</td>
<td></td>
</tr>
<tr>
<td>Number of Via Interconnects</td>
<td>1,000</td>
<td>&gt; 1,000</td>
<td>AMETEK has manufactured Multi-Chip Modules with up to 60,000 Via Interconnects</td>
</tr>
<tr>
<td>Via Diameter</td>
<td>0.008 inch</td>
<td>0.004 inch</td>
<td>0.008 inch Diameter Vias are preferred if circuit density is achievable</td>
</tr>
<tr>
<td>Layer Thickness to Via Diameter Aspect Ratio</td>
<td>0.010 inch Thick Tape for 0.008 inch Via</td>
<td>0.0075 inch Thick Tape for 0.004 inch Via</td>
<td>Via Filling constraints may be realized with increased Tape Thickness</td>
</tr>
<tr>
<td>Via-to-Via Centerline Distance (Pitch)</td>
<td>0.030 inch</td>
<td>0.015 inch</td>
<td>AMETEK has achieved 0.0089 (.225 mm) pitch with 0.004 inch diameter vias</td>
</tr>
</tbody>
</table>

Via Centerline limits need to be followed to minimize the risk of Via-to-Via cracking after sintering

Via Stacking (Hermeticity Risk): Via columns moving continuously from top to bottom of the ceramic structure must be staggered to achieve consistent hermeticity. One via must be displaced "off - center" to create a ceramic seal. Typical "off - center" displacement is 0.030 inches.
## Screen Printing Design Rules

**CIRCUIT DENSITY: Line Width, Line Separation Gap, Via Cover Pad Diameter**

<table>
<thead>
<tr>
<th>DESCRIPTION</th>
<th>Standard Process</th>
<th>Advanced Process</th>
<th>Engr Approval Required</th>
</tr>
</thead>
<tbody>
<tr>
<td>CIRCUIT FEATURE</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A VIA TO LINE PITCH</td>
<td>0.0225 inch</td>
<td>0.0165 inch</td>
<td>0.0120</td>
</tr>
<tr>
<td>B VIA TO EDGE / CAVITY</td>
<td>0.030 inch</td>
<td>0.030 inch</td>
<td>0.030</td>
</tr>
<tr>
<td>C VIA TO VIA PITCH</td>
<td>0.030 inch</td>
<td>0.025 inch</td>
<td>0.015</td>
</tr>
<tr>
<td>D LINE WIDTH</td>
<td>0.010 inch</td>
<td>0.006 min</td>
<td>0.004 min</td>
</tr>
<tr>
<td>E LINE ISOLATION GAP</td>
<td>0.010 inch</td>
<td>0.007 min</td>
<td>0.004 min</td>
</tr>
<tr>
<td>F LINE TO LINE PITCH</td>
<td>0.020 inch</td>
<td>0.013 min</td>
<td>0.008 min</td>
</tr>
<tr>
<td>G LINE TO EDGE</td>
<td>0.030 inch</td>
<td>0.025</td>
<td>0.015</td>
</tr>
<tr>
<td>H VIA DIAMETER</td>
<td>0.008 inch</td>
<td>0.006</td>
<td>0.004</td>
</tr>
<tr>
<td>I LINE TO VIA PAD</td>
<td>0.010 inch</td>
<td>0.007</td>
<td>0.005</td>
</tr>
<tr>
<td>J VIA COVER PAD</td>
<td>0.015 inch</td>
<td>0.013</td>
<td>0.010</td>
</tr>
</tbody>
</table>

**Note:** All Dimensions in Inches Unless Otherwise Specified
Braze Alloy Selection for Kovar Sealframes

Coefficient of Thermal Expansion “CTE” Match versus Braze Alloy Selection

- HTCC Packages Use Kovar Sealframes to Match the CTE of Alumina
- Braze Alloy Selection Depends on the Basis of Overall Package Size
  - Increased Braze Temperatures Cause More Stress:
  - Lower Braze Temperature = Less Stress
- HTCC Pkgs Use Silver-Copper (Ag-Cu) Braze Alloy (melting point 779°C)
  - for Package Sizes ≤ 1.7 inches
- HTCC Pkgs May Use Gold-Germanium (Au-Ge Solder) Alloy (melting point 356°C)
  - for Package Sizes ≥ 1.7 inches
- HTCC Pkgs May Use Gold-Tin (Au-Sn Solder) Alloy (melting point 280°C)
  - for Package Sizes ≥ 1.7 inches

<table>
<thead>
<tr>
<th>DESIGN FEATURES</th>
<th>DESIGN CATEGORY</th>
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</thead>
<tbody>
<tr>
<td>SEAL FRAME BRAZE</td>
<td>STANDARD</td>
</tr>
<tr>
<td>LENGTH (MAXIMUM)</td>
<td>1.7 inch</td>
</tr>
<tr>
<td>THICKNESS (MAXIMUM)</td>
<td>.125 inch</td>
</tr>
<tr>
<td>THICKNESS (MINIMUM)</td>
<td>.050 inch</td>
</tr>
</tbody>
</table>
## Plating Finishes

<table>
<thead>
<tr>
<th>PROCESS DESCRIPTION</th>
<th>Type</th>
<th>Purity</th>
<th>COMMENTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electrolytic Gold</td>
<td>III</td>
<td>99.90%</td>
<td>ASTM B 488-01 (formerly MIL-G-45204, Type III) soft gold</td>
</tr>
<tr>
<td>Electrolytic Nickel</td>
<td>Matte Finish</td>
<td>99.9%</td>
<td>Highest Ductility</td>
</tr>
<tr>
<td>Electroless Nickel</td>
<td>0.1% Boron Or 5% Low Phosphorus</td>
<td>99.9% 95.0%</td>
<td>Applied to Metallized Ceramic prior to Brazing (not final finish)</td>
</tr>
<tr>
<td>Electroless Nickel + Electroless Gold</td>
<td>Ni-P Au</td>
<td>99.9%</td>
<td>Limited Application</td>
</tr>
</tbody>
</table>

*Palladium Plating may provide a lower cost alternative to Gold in the Future*
# Electronic Packaging Material Properties

<table>
<thead>
<tr>
<th>Category</th>
<th>Material</th>
<th>Application</th>
<th>Density</th>
<th>Coefficient of Thermal Expansion</th>
<th>Dielectric Constant</th>
<th>Thermal Conductivity</th>
<th>Resistivity Volume</th>
<th>Resistivity Electrical</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chemical Name</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Aluminum Oxide</td>
<td>Al₂O₃ Black: 92%</td>
<td>HTCC Packages MLC Feedthroughs</td>
<td>3.6</td>
<td>7.4</td>
<td>7.9</td>
<td>35</td>
<td>0.08</td>
<td>1.0 x 10¹⁴</td>
</tr>
<tr>
<td>Aluminum Oxide</td>
<td>Al₂O₃ White: 94%</td>
<td>HTCC Packages MLC Feedthroughs</td>
<td>3.6</td>
<td>7.2</td>
<td>8.5</td>
<td>40</td>
<td>0.09</td>
<td>1.0 x 10¹⁴</td>
</tr>
<tr>
<td>Aluminum Nitride</td>
<td>AlN</td>
<td>HTCC Packages Thin Film Substrates</td>
<td>3.3</td>
<td>4.2</td>
<td>8.5</td>
<td>150</td>
<td>0.41</td>
<td>1.0 x 10¹⁴</td>
</tr>
<tr>
<td>Beryllium Oxide</td>
<td>BeO</td>
<td>Heatsink</td>
<td>2.66</td>
<td>7.6</td>
<td>6.8</td>
<td>259</td>
<td>0.62</td>
<td>1.0 x 10¹⁵</td>
</tr>
<tr>
<td>Diamond</td>
<td></td>
<td>Heatsink</td>
<td>3.52</td>
<td>2.3</td>
<td>2,100</td>
<td>5.0</td>
<td>1.0 x 10¹⁶</td>
<td></td>
</tr>
<tr>
<td>Silicon Carbide</td>
<td>SiC</td>
<td>Heatsink</td>
<td>3.10</td>
<td>3.7</td>
<td>65 - 270</td>
<td>0.64</td>
<td>1.0 x 10¹³</td>
<td></td>
</tr>
<tr>
<td>Devices</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Silicon</td>
<td>Si</td>
<td>Semiconductor; Integrated Circuit Thin Film Substrate</td>
<td>2.30</td>
<td>3.8</td>
<td>151</td>
<td>0.36</td>
<td>2.3 x 10⁵</td>
<td></td>
</tr>
<tr>
<td>Gallium Arsenide</td>
<td>GaAs</td>
<td>Semiconductor; Integrated Circuit (3GHz - 150GHz)</td>
<td>5.32</td>
<td>6.5</td>
<td>54</td>
<td>0.13</td>
<td>3.6 x 10⁸</td>
<td></td>
</tr>
<tr>
<td>Heat Sink Materials</td>
<td>Category</td>
<td>Material</td>
<td>Application</td>
<td>Density</td>
<td>Coefficient of Thermal Expansion</td>
<td>Dielectric Constant</td>
<td>Thermal Conductivity</td>
<td>Resistivity Volume</td>
</tr>
<tr>
<td>---------------------</td>
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<td>---------------------</td>
</tr>
<tr>
<td>Copper</td>
<td>Chemical Name</td>
<td>Copper</td>
<td>Heatsink; Leads</td>
<td>8.96</td>
<td>16.3</td>
<td>397</td>
<td>0.95</td>
<td>2.65</td>
</tr>
<tr>
<td>Oxygen Free High Conductivity Copper OFHC</td>
<td>Pinch-Off Tubes; Power Package</td>
<td>8.90</td>
<td>18.3</td>
<td>365</td>
<td>0.87</td>
<td>1.72</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Aluminum: Al</td>
<td>Heatsink</td>
<td>2.7</td>
<td>24.0</td>
<td>180</td>
<td>0.52</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tungsten: W</td>
<td>Heatsink</td>
<td>19.3</td>
<td>4.5</td>
<td>180</td>
<td>0.52</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Molybdenum: Mo</td>
<td>Heatsink</td>
<td>10.2</td>
<td>5.1</td>
<td>140</td>
<td>0.33</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kovar: Fe-Ni-Co</td>
<td>Leads; Pins; Heatsink; Sealing Package</td>
<td>8.3</td>
<td>5.7 - 6.2</td>
<td>16.7 - 18.4</td>
<td>0.040 - 0.044</td>
<td>48</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Iron-Nickel-Cobalt</td>
<td></td>
<td>8.1</td>
<td>7.5 - 8.5</td>
<td>14.6 - 16.7</td>
<td>0.035 - 0.040</td>
<td>58</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Alloy 42: Fe-Ni</td>
<td>Leads; Pins</td>
<td>90% W - 10% Cu</td>
<td>Heatsink</td>
<td>17.17 - 17.00</td>
<td>5.7</td>
<td>157 - 209</td>
<td>0.37 - 0.50</td>
<td>4.8</td>
</tr>
<tr>
<td>Iron - 42% Nickel</td>
<td></td>
<td>85% Mo - 15% Cu</td>
<td>Heatsink</td>
<td>10.01</td>
<td>7.0</td>
<td>160</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Thank You

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