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Advanced cooling of power electronics with copper cold sprayed aluminium heatsinks & busbars.

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Abstract

Cold spray (CS) technology is a well-established technique for metallic deposits in various industries. CS process is known to deposit the powder particles in a solid state far below the melting point of the materials; as a result, common problems associated with temperatures, such as high-temperature oxidation, thermal stresses, and phase transformation, can be avoided. Moreover, cold spray offers short production times, unlimited component size capability, and flexibility for localized deposition. In recent years, CS technology has been extensively used for electrical applications, e.g., cold-sprayed copper for heat sinks, busbars, heat exchangers, and refrigeration units. The present work demonstrates the properties of cold-sprayed copper and its utilization for hybrid heat sink and busbar applications. The results illustrate that the properties of cold-sprayed Cu in the as-sprayed state are comparable with bulk-Cu with 98% IACS electrical conductivity and thermal conductivity of 368 W/mK. Perfectly gas-tight Cu-deposits with a He-leakage rate smaller than 1×10^{-7} mbar-l/s have been produced.

1 Hybrid Heat Sink

Electronic devices, e.g., in telecommunications and high power systems, generate heat during regular operation that must be dissipated to avoid junction temperatures exceeding tolerable limits, as this can lead to performance inhibition and deterioration of reliability. It has been shown that every 10 K reduction in the junction temperature will increase the device's life and performance. Thus, maintaining the junction temperature below the maximum allowable limit is a primary issue.

The most common way to cool devices has been air/liquid cooling using a heat sink. Conventionally, copper and aluminum heat sinks are combined with such cooling systems. Copper is always a preferred choice for heat sinks due to its cooling capacity superior to aluminum; however, copper's weight and cost limit the size, especially for large electronics systems. Due to lower thermal conductivity, aluminum heat sinks do not spread the heat quickly enough; thus, a large surface area or taller fins are required, which is not a plausible option in many cases. Moreover, a problem arises if a heat sink is substantially more significant than the integrated circuit devices it resides on. If the electronic device generates heat faster than the heat sink spreads, portions of the heat sink far away from the device do not contribute much to heat dissipation. In other words, if the base is a poor heat spreader, much of its surface area is wasted. Furthermore, to connect the aluminum heat sink with electronic devices, a thermal interface material is generally used because soldering of aluminum with direct bond copper of the electronic device is difficult. Typically, this material has a very low thermal conductivity, affecting the overall aluminum heat sink's performance. A hybrid heat sink, combining the thermal benefits of copper with lightweight aluminum, presents an exciting alternative to overcome the issues associated with conventionally available copper and aluminum heat sinks. In such a concept, the portion of the heat sink that comes in contact with the electronic device is made of copper, while the other part is made of cheaper and lighter aluminum. A cold-sprayed copper layer was deposited on a base plate of a commercially available extruded aluminum heat sink (as shown in Figure 2). The thickness of such a copper

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layer can be adjusted to the electronic devices' design and operational temperature.

To demonstrate the performance of hybrid-heat sinks, Impact Innovations conducted experiments to compare the performance of identically structured copper, aluminum, and hybrid-heat sinks. The experiment was performed three times, each time with a different heat-sink design.

Thermal impedance and thermal resistance were measured. The thermal impedance of heat sinks was evaluated by running power cycles at specific load currents, heating the device until reaching the thermal equilibrium. Then, the load current was switched off, and the voltage drop was recorded. When an aluminum heat sink was tested, a maximum temperature of 438 K was registered.

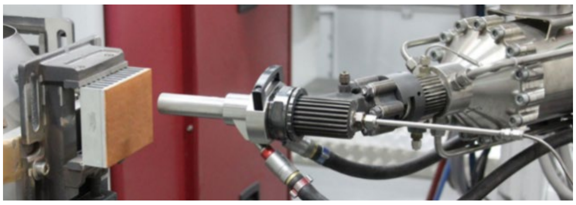

Fig. 1. Cold sprayed hybrid-heat sinks.

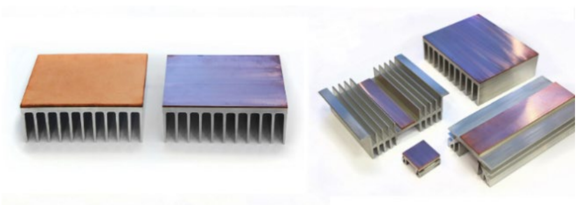

Fig. 2. Cold sprayed hybrid-heat sinks.

This value corresponds to a thermal resistance of 0.7 K/W. For the copper heat sink, the maximum temperature was just 348 K, and the corresponding thermal resistance was 0.33 K/W. Testing the hybrid-heat sink, the maximum temperature was slightly higher at 349 K, and the thermal resistance was 0.36 K/W.

These results show that the copper and hybrid heat sinks have almost identical thermal results and substantially outperformed the aluminum heat sink, thus showing the importance of quick heat spreading along the base. At the same time, the hybrid heat sink weighed less than the copper heat sink.

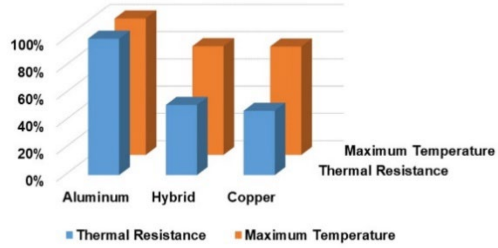

Fig.2. Thermal resistance and maximum temperature obtained at the device using aluminum, hybrid, and copper heat sinks.

Indeed, hybrid heat sinks manufactured by cold spraying have higher production costs than commercially available aluminum heat sinks; however, adding a layer of copper to an aluminum heat sink decreases its thermal resistance by 48%, as shown in Figure 3. This has a direct effect on the production costs since the semiconductor area can be reduced by 94%. Besides, the deposition efficiency and deposition rates of copper powder by the cold spray process are 95% (including overspray) and 10 kg/h, respectively, indicating the potential of the CS process to realize a cost-effective large-scale industrial production.

2 Busbars

Busbars are sophisticated technology that simplifies, reduces costs, and increases the flexibility of intricate power distribution. A busbar is vital for transmitting significant current levels between functions inside the assembly in power-intensive electrical applications. Copper and aluminum are the two most common conductors used in electrical equipment, including busbar trunking systems. Traditionally, copper is the conductor of choice for busbar trunking systems; however, in recent years, aluminum conductors have become more prevalent in the global busbar trunking market, offering specific advantages over copper. When compared by volume, copper outperforms aluminum regarding electrical ratings—boasting a lower electrical resistance, lower power loss, lower voltage drop, and higher ampacity. All of which contribute to the electrical efficiency of the busbar trunking system. However, when compared by weight, aluminum is more electrically efficient. Again, this can be attributed to aluminum having a density 70% lower than

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copper, making it the perfect choice where busbar sizing is a non-issue.

Impact Innovations' cold spray system presents an exciting alternative, where a copper busbar trunking system can be replaced by aluminum, combining the thermal benefits of copper with lightweight aluminum. Impact Innovations' cold spray system with a special powder injecting assembly can deposit flat copper tracks on aluminum busbar profiles without masking.

Cu-tracks were produced on an Al-alloy plate without masking, demonstrating the sharp edges of the coating tracks, as shown in Figure 1a, with the following characteristics:

- Adjustable coating thickness with narrow tolerance (e.g., ±50 µm)
- Al plate length 580 mm
- No masking used
- Deposition efficiency >98%
- Porosity <0,5%
- Uniform coating thickness
- Deposition rate up to 10 kg/h
- Sharp edges of the spray spot

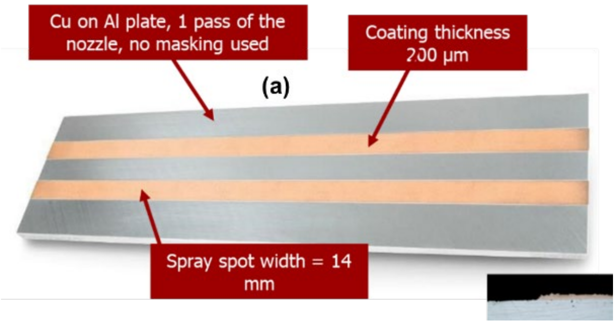

Fig. 2 (a) Cold Spray deposited Cu contact tracks on Aluminum

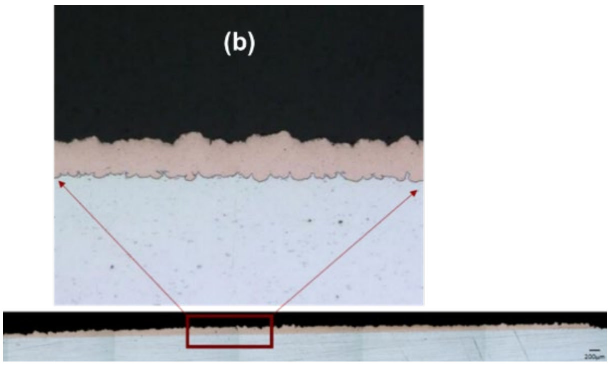

Fig. 1 (b) A uniform and dense Cu coating on Al plate.

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