Cooling Technologies Research Center (CTRC)

Purdue University, Suresh Garimella, 765.494.6209, sureshg@purdue.edu

Transient Liquid Phase Sintering Systems for Power Electronics

In microelectronic systems, referred to as integrated circuits (ICs) or computer chips, are bonded to circuit boards using low melting point metals. This makes it possible for electrical signals to be transmitted properly. When done properly, systems function well. Other important roles of low melting point metals are to transmit heat away from the computer chips, to prevent them from overheating during operation, and to compensate for mechanical stresses as different parts of the system heat up and cool down.

The operating temperatures of successive generations of computer chips have continued to increase with increases in performance requirements. An example of this would be the extreme operating environments for truck and car engines. As operating temperatures increase, low melting point metals are not strong enough to function. In addition, bonds between the outer surfaces of chips and cooling fins, which are typically formed by thermal greases, require more thermally robust materials as the operating temperature increases. Because of these limitations and challenges, enhancements are needed. This project is focused on designing innovative metal-based technologies and processes to replace low melting point metals, thermal greases, and other conventional thermal interface materials used for attaching components to circuit boards, silicon die to substrates, and components to heat rails and cooling fins.

One class of end products for this research is in power electronics for new transportation systems, such as electric and hybrid vehicles. Credit: Toyota

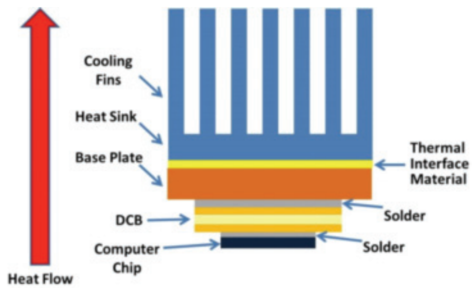
The approach we are using is known as "transient liquid phase sintering (TLPS)" in which a low melting point metal reacts with other materials in a joint to form a new phase with no remaining liquid, hence the liquid phase is "transient." In practical terms, a low melting temperature metal powder and an organic flux are mixed with high melting point alloys that are in particle form. These are applied to two substrates to be joined. When temperatures are increased above the melting temperature of the low melting point phase, a new compound begins to form at the interfaces between the liquid and the high melting point alloy and between the liquid and the substrates, as seen in the figure. For specific alloys, annealing temperatures, and particle geometries for the low and high melting temperature phases, the liquid phase will completely disappear, leaving behind a bonding material that has a significantly higher melting point than the original alloy. Having these new, more thermally stable bonding materials opens doors for even higher temperature and higher performance applications of electronics.

Formation of the intermetallic phase is not all that is required to make effective and reliable bonds. Current commercially available TLPS formulations exhibit high macro porosity and thus poor mechanical and thermal performance. CTRC researchers have identified seven key processes that must be considered to design an effective TLPS system. In this project we are developing and integrating models of the seven processes to identify composition and processing pathways to optimized TLPS technologies for specific high temperature and mechanical performance applications.

In 2014, this project developed models for the two most important processes for designing alloys. Researchers tested models containing as many as five elements and fabricated model paste formulations for attaching cooling systems to chips, semiconductor dies, and substrates in power electronics. The models are based on thermodynamic, kinetic, and technological analyses that answer the following questions: 1) What solids form when different elements are mixed together and heated? 2) Is there any liquid predicted to be remaining? 3) Can the process be accomplished in a practical time (< 1 hour) and at a temperature that does not damage the electronics? Answering these questions has led the team to innovative down-selection criteria and novel alloy formulations that work at higher temperatures where current commercial systems are unreliable.

The ultimate goal of this research has been and will continue to be to develop high performance and commercially viable thermal interface materials and bonding materials and processes based on transient liquid phase sintering. Our approach of integrating materials modeling and simulation, uses existing thermodynamic databases and tools, experiments designed to test and refine the models, and software tools for I/UCRC members to use for future TLPS application. It fits clearly within the Materials Genome Initiative (MGI) (https://www.whitehouse.gov/mgi). The MGI aims to double the speed at which we discover, develop and manufacture new materials through computational tools, experimental tools, digital data, and collaborative networks. One additional way in which this project works toward CMI goals is in correcting errors in existing public and commercial databases where the data has not previously been experimentally verified. In addition to its use in designing TLPS bonding technologies, the models may be useful for other solder-based technologies in which significant amounts of intermetallic compounds form, such as microbumps and in advanced memory devices.

Economic impact: The development of model systems and software tools represent key steps towards improved understanding and control of TLPS and bonding processes. In the last few months, CTRC researchers have formulated novel TLPS systems for a range of processing and use conditions. Preliminary experiments indicate that their bond strength is higher than existing TLPS formulations. The current highest priority is to quantify the mechanical and thermal properties as functions of TLPS composition, processing conditions, geometry, and temperature, and to further refine the models. This research will benefit the electronics and automotive industries by identifying high performance, solid thermal interface and bonding materials for improved cooling of power electronics, particularly as operating temperatures increase.



Schematic of electrical, thermal, and mechanical system needed for a computer chip to function. Solder and thermal greases play critical roles in heat flow from the chip to the outside air. Transient liquid phase sintering systems can replace both solder and thermal interface materials, increasing bond performance at higher temperatures needed for automotive and power electronics applications.

For more information, contact Carol Handwerker at Purdue University, handwerker@purdue.edu, Bio https://engineering.purdue.edu/MSE/People/ptProfile?id=11509, 765.494.0147.

Thin Heat Pipes for Low Power Applications

Heat pipes are an industry-proven technology that offers potential orders-of-magnitude heat spreading performance improvements when compared to solid heat spreaders. The heat spreading efficiency of heat pipes reduces the overall power consumption of cooling solutions because auxiliary cooling components, such as axial fans (which dump heat to the ambient atmosphere) do not need to work as hard. While heat pipes are conventionally employed in larger-scale laptop and desktop computers, recent efforts within Purdue University's Cooling Technologies Research Center (CTRC) have focused on heat pipes that may be used in mobile platforms such as cell phones and tablets. The efficient heat transport that heat pipes enable is due to the phase change of an internal working fluid. It changes from liquid to vapor. Porous structures imbedded inside then passively drive the working fluid.

However, existing heat pipe design metrics focus on removing the maximum possible amount of heat from devices, rather than optimizing performance for operation at ultra-thin form factors. With the trend of decreasing thicknesses of mobile electronic devices, there is an unmet need to better understand the performance of heat pipes for these applications. Using analytical and numerical models, CTRC researchers have evaluated and compared the performance of thin heat pipes to that of a baseline commercial heat spreader.

This breakthrough CTRC work has generated comprehensive guidelines for the range of geometries and boundary conditions under which ultra-thin heat pipes may provide a comparative performance benefit against the current solid heat spreaders used in industry. A novel figure of merit was identified for the form factors and operating conditions of interest for mobile thermal management.

Economic impact: Heat pipes are ubiquitously deployed in consumer electronic products. Worldwide, smart phone shipments are expected to surpass 2.3 billion units per year by 2017. As a result, it is reasonable to assume that the economic impact of this breakthrough could be substantial. Intel, a CTRC member, recently launched a $1.5M "platform thermals" research program through their University Research Office that is targeted at thermal management in this market. CTRC Faculty have been awarded funding through this program to further investigate transformational advancement of heat pipe technologies for ultra-thin mobile platforms.

Ultra-thin heat pipe devices may enable higher performance mobile electronic devices that are cool to the touch.

For more information, contact Justin A. Weibel at Purdue University, jaweibel@purdue.edu. Bio https://engineering.purdue.edu/ME/People/ptProfile?id=78578, 765.494.4762.