Diamond Heat Spreader

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Diamond Heat Spreader

ABSTRACT

Specialized ASICs, e.g., GPUs, often have a non-uniform power consumption map due to the nature of their workloads. This causes a non-uniform temperature distribution across the area of the ASIC, with the appearance of acute temperature hotspots. This disclosure describes various configurations of diamond heat spreaders that can spread the heat across the full extent of an attached heat sink or cold plate, bringing the temperature map of a semiconductor package closer to uniformity. Diamonds, having a thermal conductivity nearly an order of magnitude greater than metals, can efficiently reduce the peak hot spot temperature, reduce temperature gradients, improve silicon performance (e.g., by 100 MHz for every 10°C), support higher heat flux, etc. Per the techniques, diamond crystals, independently fabricated using industrial processes, can be deployed in various configurations in thermal contact with the heat-generating ASIC dies or semiconductor packages. The configuration can be selected based on heat dissipation requirement and the type of package.

KEYWORDS

- Heat spreader
- Thermal load
- Heat dissipation
- Heat sink
- Cold plate
- Thermal interface
- Semiconductor package
- ASIC die
BACKGROUND

Specialized application specific integrated circuits (ASICs), e.g., GPUs, often have a highly non-uniform power consumption map due to the nature of their workloads. This causes a non-uniform temperature distribution across the area of the ASIC, with the appearance of acute temperature hotspots.

![Image of non-uniform temperature map]

**Fig. 1: A non-uniform temperature map due to non-uniform power consumption**

This is illustrated in Fig. 1, where the difference in temperature between the hot (red) and cool (blue) regions of the ASIC can be as high as 50°C.
DESCRIPTION

This disclosure describes diamond heat spreaders that can spread heat across the full extent of an attached heat sink or cold plate, bringing the temperature map of the ASIC closer to uniformity. Diamonds, having a thermal conductivity nearly an order of magnitude greater than metals, can efficiently reduce the peak hot spot temperature, reduce temperature gradients, improve silicon performance (e.g., by 100 MHz for every 10°C), support higher heat flux, etc.

Fig. 2: Temperature map of an ASIC with a diamond heat spreader

Fig. 2 illustrates an example temperature map for an ASIC with uniform power map. Using a diamond heat spreader, per the techniques of this disclosure, can bring the resulting temperature map much closer to the uniform case. As compared to traditional techniques (Fig. 1), the peak hot spot temperature is reduced by >20°C, and the difference between the coolest and hottest areas of the ASIC is reduced to significantly lower. Diamond crystals, independently
fabricated using industrial processes, can be deployed in various configurations as heat spreaders as described in the various sections below.

_Diamond spreader on center chip_

![Diagram of Diamond spreader on center chip](https://www.tdcommons.org/dpubs_series/3722)

As illustrated in Fig. 3, after suitable grinding, the diamond heat spreader can be situated on the center chip of a multi-chip die. To accommodate the heat spreader, a niche can be made in the cold plate (or heat sink) that is coupled to the center die. A thermal interface material (TIM) can interface between the die and the cold plate or heat sink. The diamond spreader can be attached to the center die using a low temperature and highly conductive adhesive or thermal interface material; a lower temperature solder, e.g., indium, with metallization on both the silicon and the diamond surfaces; surface-activated bonding between the diamond and the silicon; etc. The technique of situating the diamond spreader on the center chip is suitable in configurations where the central chip (chip 0) emits a greater heat than the side chips (chips 1 and 2).
Diamond spreader on the full package

As illustrated in Fig. 4, after suitable grinding, the diamond heat spreader can be situated across the surface of the entire package of a multi-chip die. A thermal interface material (TIM) can interface between the die and the cold plate or heat sink. The diamond spreader can be attached to the center die using a low temperature and highly conductive adhesive or thermal interface material; a lower temperature solder, e.g., indium, with metallization on both the silicon and the diamond surfaces; surface-activated bonding between the diamond and the silicon; etc.
Diamond spreader on thinned center chip: Approach 1

As illustrated in Fig. 5, after suitable grinding, the diamond heat spreader can be situated on the thinned down central chip. The central chip can be thinned, e.g., by chemical or mechanical processes. A thermal interface material (TIM) can interface between the die and the cold plate or heat sink. The diamond spreader can be attached to the center die using a low temperature and highly conductive adhesive or thermal interface material; a lower temperature solder, e.g., indium, with metallization on both the silicon and the diamond surfaces; surface-activated bonding between the diamond and the silicon; etc. The central chip (chip 0) is attached with its integrated diamond spreader and to other chips and the interpose wafer using techniques similar to chips and wafer on substrate technology. The package is molded and ground to flatten its top surface before attaching to a cold plate or heat sink via a thermal interface material.
Fig. 6: Diamond spreader on thinned center chip: Approach 2

Fig. 6 illustrates a second approach to situating the diamond spreader on a thinned central chip. Although this approach produces an outcome similar to the previous approach (Approach 1), the manufacturing steps differ between the two. In Approach 2, after the center die is thinned, it and other components, e.g., high-bandwidth memory (HBM), are attached to the interposer using a standard process. The diamond spreader is attached to the center die using a low temperature and highly conductive adhesive or thermal interface material; a lower temperature solder, e.g., indium, with metallization on both the silicon and the diamond surfaces; surface-activated bonding between the diamond and the silicon; etc. The package is molded and ground to flatten its top surface, and the cold plate or heat sink is attached via a thermal interface material.
Diamond spreader on thinned corner chips

As illustrated in Fig. 7, the diamond heat spreader can be situated on thinned corner chips. Such a configuration is suitable for corner chips that emit the bulk of the heat emanating from a package. The configuration uses local heat spreading to minimize the impact on the cold plate or heat sink for heterogeneous semiconductor packages. After the corner dies are thinned down, the corner dies and other components, are attached to the interposer using a standard process. The diamond spreader is attached to the corner dies using a low temperature and highly conductive adhesive or thermal interface material; a lower temperature solder, e.g., indium, with metallization on both the silicon and the diamond surfaces; surface-activated bonding between the diamond and the silicon; etc. The package is molded and ground to flatten its top surface, and the cold plate or heat sink is attached via a thermal interface material.
Diamond spreader at the base of the cold plate or heat sink

As illustrated in Fig. 8, the diamond heat spreader can be situated at the base of the cold plate or heat sink. The diamond spreader can be attached to the cold plate or heat sink using a low temperature and highly conductive adhesive or thermal interface material; using a lower temperature solder, e.g., indium, with metallization on both the cold plate base and the diamond spreader; by metallization of the diamond spreader followed by brazing of both the cold plate and the diamond spreader; etc. The cold plate (or heat sink) with its integrated diamond heat spreader is attached to the package using, e.g., a standard thermal interface material; a direct bonding of the diamond base to the silicon through intermetallic layers or solder; etc.
As illustrated in Fig. 9, the diamond heat spreader can be embedded in a niche created at the base of the cold plate or heat sink. The diamond spreader can be attached to the cold plate or heat sink using a low temperature and highly conductive adhesive or thermal interface material; using a lower temperature solder, e.g., indium, with metallization on both the cold plate base and the diamond spreader; by metallization of the diamond spreader followed by brazing of both the cold plate and the diamond spreader; etc. The cold plate (or heat sink) with its integrated diamond heat spreader is attached to the package using, e.g., a standard thermal interface material; a direct bonding of the diamond base to the silicon through intermetallic layers or solder; etc.
As illustrated in Fig. 10, the diamond heat spreader can be embedded in a niche created at the base of a heat sink or heat pipe. Such a configuration improves the capacity and/or performance of the heat pipe, and also increases the critical heat flux, mitigating the occurrence of coolant dry-out within the heat pipe. The diamond spreader can be attached to the base of the heat sink using a low temperature and highly conductive adhesive or thermal interface material; using a lower temperature solder, e.g., indium, with metallization on both the heat sink base and the diamond spreader; by metallization of the diamond spreader followed by brazing of both the heat sink and the diamond spreader; etc. The heat sink with its integrated diamond heat spreader is attached to the package using, e.g., a standard thermal interface material; a direct bonding of the diamond base to the silicon through intermetallic layers or solder; etc.

**Diagram heat sink or cold plate integrated into the package**
Fig. 11: Diamond heat sink or cold plate integrated into the package

Fig. 11 illustrates a cold plate or heat sink made of diamond. The fins of such a cold plate or heat sink can also be made of diamond. The diamond fins can be attached to the base of the cold plate or heat sink using a low temperature and highly conductive adhesive or thermal interface material; using a lower temperature solder, e.g., indium, with metallization on both the cold plate base and the diamond spreader; by metallization of the diamond spreader followed by brazing of both the cold plate and the diamond spreader; by laser cutting the diamond wafers followed by sealing of the top-cover; etc. The diamond cold plate or heat sink can be attached to the package using, e.g., a standard thermal interface material; a direct bonding of the diamond base to the silicon through intermetallic layers or solder; etc.

CONCLUSION

This disclosure describes various configurations of diamond heat spreaders that can spread the heat across the full extent of an attached heat sink or cold plate, bringing the temperature map of a semiconductor package closer to uniformity. Diamonds, having a thermal conductivity nearly an order of magnitude greater than metals, can efficiently reduce the peak
hot spot temperature, reduce temperature gradients, improve silicon performance (e.g., by 100 MHz for every 10°C), support higher heat flux, etc. Per the techniques, diamond crystals, independently fabricated using industrial processes, can be deployed in various configurations in thermal contact with the heat-generating ASIC dies or semiconductor packages. The configuration can be selected based on heat dissipation requirement and the type of package.