Method for CNT-based microchannels for IC liquid cooling

Disclosed is a method for carbon nanotube (CNT) based microchannels for integrated circuit (IC) liquid cooling. Benefits include improved functionality, improved thermal performance, improved reliability, and improved ease of manufacturing.

Background

In a package-based liquid cooling loop, liquid (such as water or antifreeze) is pumped through a cold plate that is in contact with the back of an IC die. The cold plate includes a set of parallel microchannels of ~50-micron width that increase the surface area. The contact of the liquid with the cold plate generates resistance. However, the microchannels enhance the heat-transfer coefficient due to the extremely small hydrodynamic diameter. The heat-transfer coefficient is inversely proportional to hydrodynamic diameter (channel dimension).

The mechanical mismatch of components in packaging negatively impacts transistor performance and reliability in a package or multi-chip packaging (MCP).

As the frequency and power density of processors increase, the requirement for cooling increases. Future processors and packages are expected to have increasing capabilities and cooling requirements. No conventional solution is expected to be sufficient to meet the future demands. Proposed solutions include copper or silicon microchannel packages. However, the thermal performance of silicon microchannels is limited, and copper microchannels have coefficient of thermal expansion (CTE) mismatch issues with silicon dice (see Figure 1).

General description

The disclosed method is a microchannel structure with carbon nanotube (CNT) material as the walls/fins in a polymer/metal matrix. The method provides the high thermal conductivity of the CNT along the wall and enhances tube-to-tube lateral heat transfer. Additionally, the method lowers the interfacial stress between the die and the microchannel heat plate due to the weak in-plane coupling of the CNT material.

The key elements of the disclosed method include:

- Growth of aligned CNT material directly on the base
- Polymer or metal matrix to interconnect the CNT material
- Water-based fluent

Advantages

The disclosed method provides advantages, including:

- Improved functionality due to providing CNT-based microchannels for IC liquid cooling
- Improved thermal performance due to the high thermal conductivity of CNT material

- Improved thermal performance due to good thermal contact between the CNT and the substrate
- Improved reliability due to minimizing the CTE mismatch/stress
- Improved reliability due to using a polymer or metal matrix that increases the wettability of hydrophobic CNT material
- Improved ease of manufacturing due to fabricating the CNT microchannels separately from the Si wafer
- Improved ease of manufacturing due to introducing the CNT microchannels in packaging

Detailed description

The disclosed method is CNT-based microchannels for IC liquid cooling. Aligned carbon nanotubes are grown directly on the substrate. It can be a higher-CTE material, such as copper, or a lower-CTE material, such as ceramic. The thickness of the substrate is based on the heat-spreading requirement of the specific package design, typically ~300-µm to 3-mm. The general catalyst that enhances the CNT growth, such as Ni or SiO_2, can be patterned with a conventional lithographic process. The pitch is typically ~100 µm. The microchannels are formed between the CNT walls (see Figure 2).

The microchannels are part of a cooling system that contains the following items (see Figure 3):

- CNT microchannel cold plate on top of the processor
- Tubing
- Water-based fluent
- Cooling fan
- Pump

The microchannel cold plate assembly has a silicon or copper cover plate (see Figure 4).

The disclosed method can be implemented using the following steps:

1. Pattern the substrate for CNT growth (see Figure 5).
2. Grow the CNT in a high temperature oven at ~800 ^{o}C (see Figure 6).
3. Mold polymer or a metal matrix with the fin to enhance the lateral heat transfer and engineer the wettability with the coolant used in the microchannel (see Figure 7).
4. Complete the cover and fluid path for the CNT microchannel (see Figure 8).
5. Bond the microchannels to the substrate and bond the die to the opposite side of the substrate or, alternatively, bond the die to substrate and bond the microchannels to the opposite side of the substrate. The die can be thinned or thick (see Figure 9).
6. Complete the package (see Figure 10).

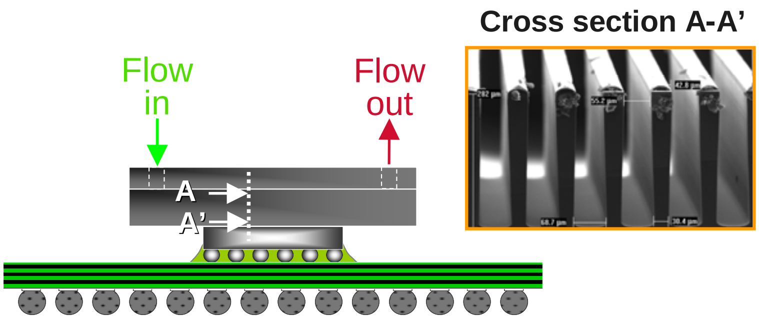

Fig. 1

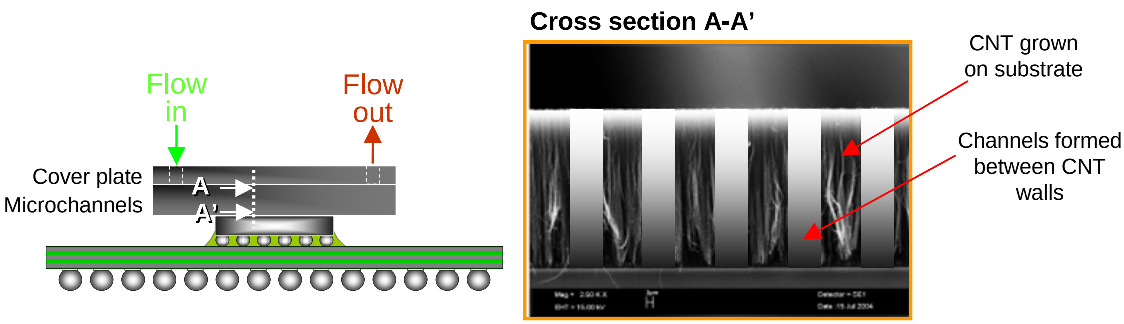

Fig. 2

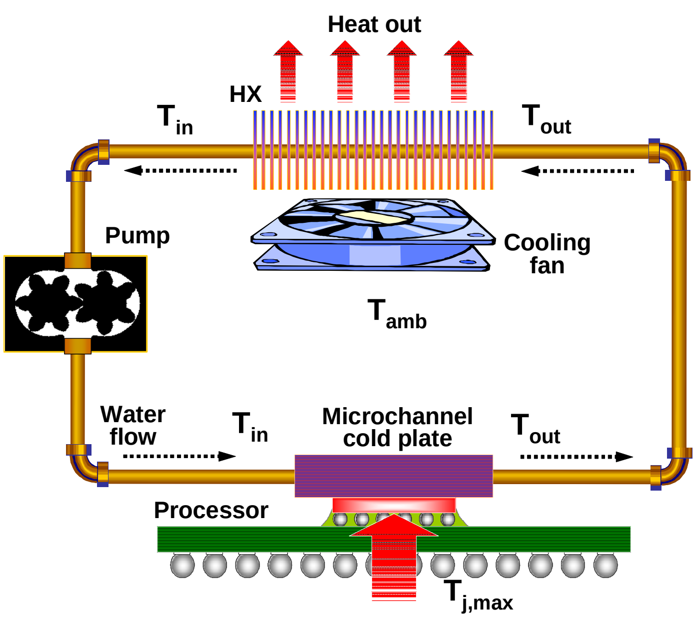

Fig. 3

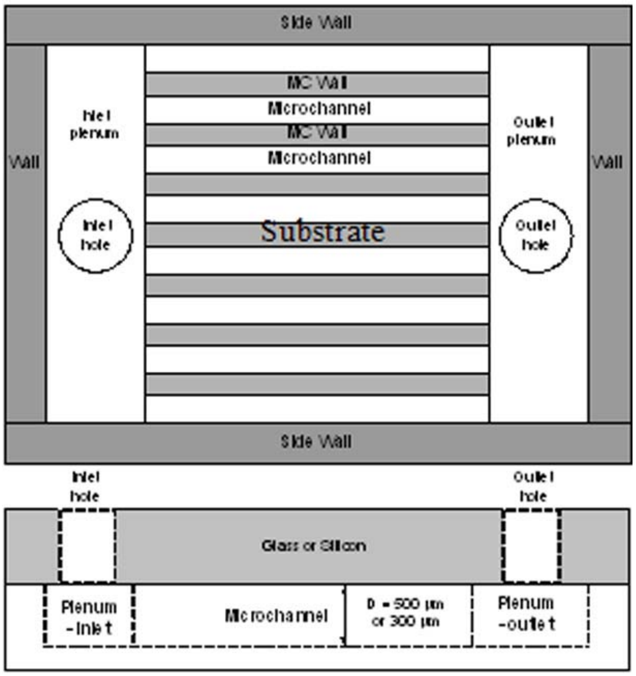
Side Wall
MC Wall
Microchannel
MC Wall
Microchannel
Inlet plenum
Outlet plenum
Wall
Wall
Substrate
Inlet hole
Outlet hole
Side Wall
Inlet hole
Outlet hole
Glass or Silicon
Plenum -inlet
Microchannel
D = 500 µm or 300 µm
Plenum -outlet

Fig. 4

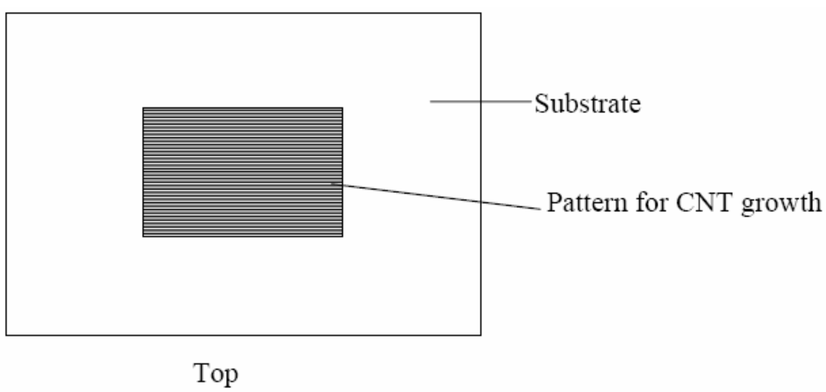
Substrate
Pattern for CNT growth
Top

Fig. 5

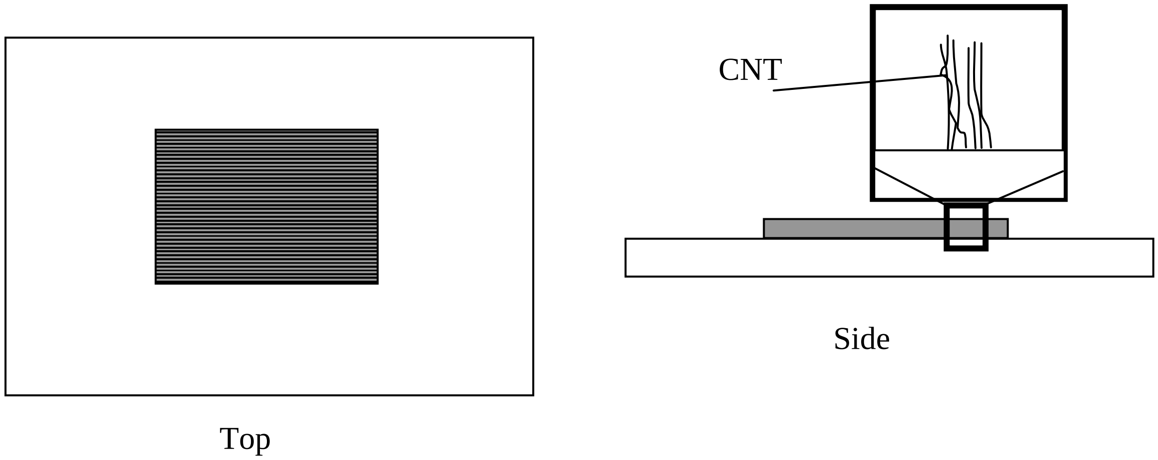

Fig. 6

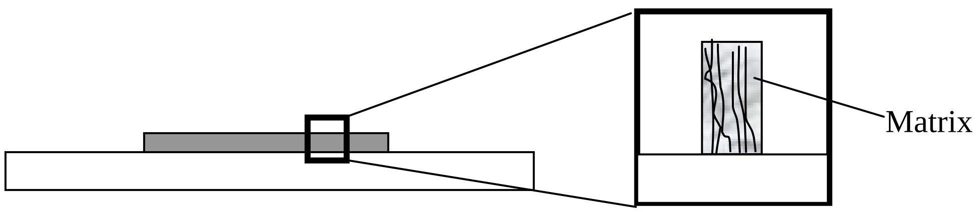

Fig. 7

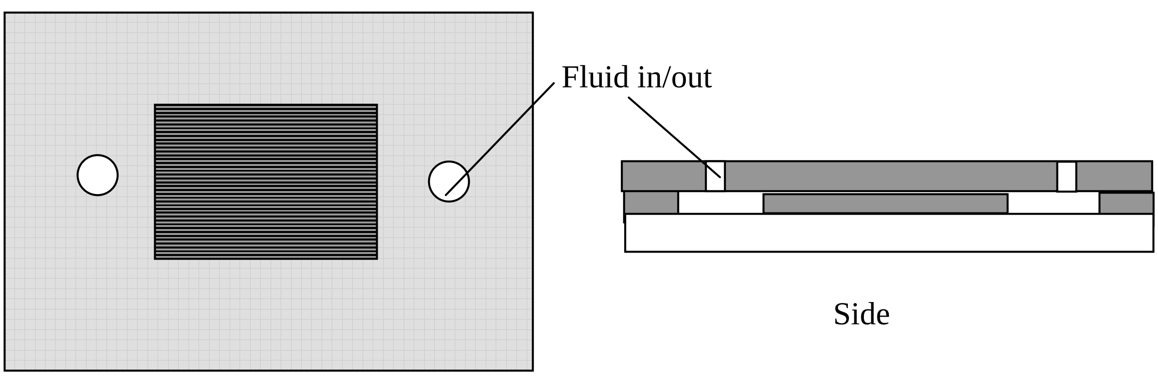

Fig. 8

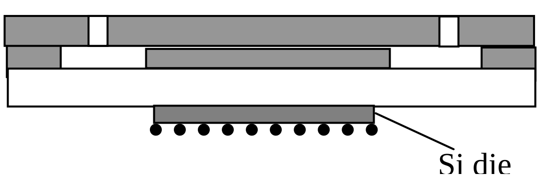

Fig. 9

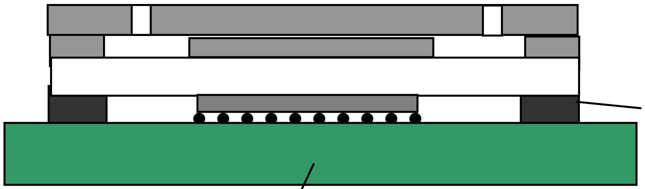

Fig. 10

Disclosed anonymously