Embedded Fibers Enhance Nano-Scale Interconnections

V. Desmaris, S. Shafiee, A. Saleem, A. Johansson and P. Marcoux

Smoltek AB, Gothenberg Sweden

Abstract
While the density of chip-to-chip and chip-to-package component interconnections increases and their size decreases the ease of manufacture and the interconnection reliability are being reduced. This paper will introduce the use of embedded fibers in the interconnections as a means of addressing these issues.

Flip chips bumps are evolving from large solder balls down to small thin copper pillars. Some copper pillars are solder capped and use a thermo-compression reflow attachment process. Smaller diameter copper pillars, while desirable by users, present a significant challenge to assemblers and reliability issues for end-users.

Nanostructures in the form of carbon nano-tubes have been evaluated for years. The recently created a means of growing metallic carbon nano-fibers, CNF's, to micro bumps which are solderable. When embedded with solder the fiber bumps produce robust component interconnections which can be less than 10 um in diameter and up to 20 um high. Attachment of the fiber micro bumps uses conventional thermo-compression bonding.

Results from the most recent evaluations will be presented indicating electrical performance and showing ease of manufacture resulting of such solder coated carbon nano-fiber micro bumps.

Introduction
Carbon nanofibers (CNFs), or vapor grown carbon nanofibers (VGCNFs) are commonly defined as cylindric nanostructures with graphene layers arranged as stacked cones, cups or plates. Carbon nanofibers with graphene layers wrapped into perfect cylinders are called carbon nanotubes [1]

The fabrication of CNFs involves placing finished IC wafers into a Catalytic Chemical Vapor Deposition (CCVD) system. In this plasma chamber carbon atoms are mixed with a transition metal catalyst, such as platinum resulting in growth of carbon rich fibers around the catalytic metal particles located as metal pads. The carbon deposits on the catalyltic metal particles to form fibers. The diameter and length of the fibers is a function of a number of factors, with the particle size of the metal being a major factor.

The fibers used by the company for electronic applications are typically 30 nm in diameter and 10 to 30 µm in length. Clusters of thousands of fibers result in the form of a "forest". See Figure 1

Since the catalytic metal is part of the metal pad on the IC then the fiber "trees" are rooted to the pad. By the term rooted we mean that the fibers are attached to the metal pads as opposed to being blended into a solution of solder that's deposited on the pads.

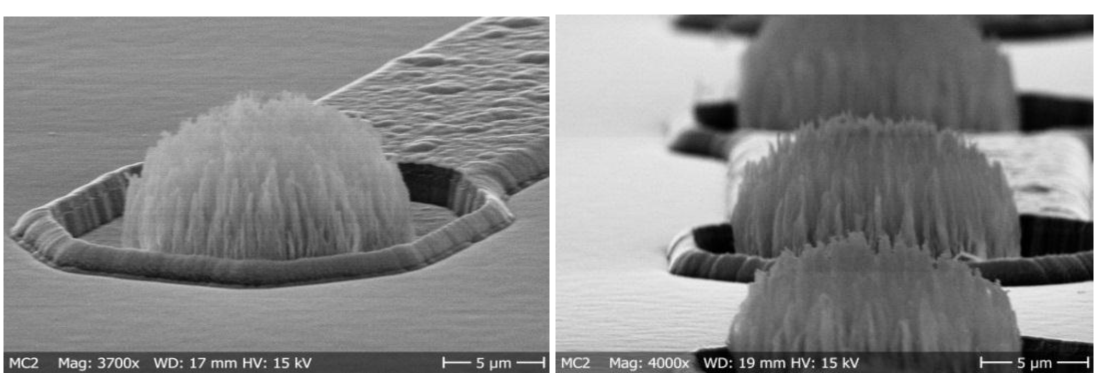

Figure 1 A forest of CNFs rooted to a metal IC bond pad. The pad size is approximately 20µm x 20 µm. An individual CNF is approx. 30µm in diameter and 10 to 15um in height

Fig. 2 Cross sectional view of CNFs rooted in a metal pad and wetted with solder. The dark area is the catalytic metal particle and the lighter area is the attached CNF.

CNF's as Reliability Enhancers

CNF's have been shown to reduce the Coefficient of Thermal Expansion (CTE) of solder when embedded in the solder [2]. Commonly used SAC solders can have CTEs ranging from 16.7 to 26 ppm/°C [3] whereas the CTE of the adjoining silicon can range from 3 ppm/°C to 8 ppm/°C creating a mismatch which can cause solder joint cracking over time and thermal cycling.

CNFs have the ability to bond with solder enabling them build composite materials, which take advantage of their high (TPa) young modulus to provide robust joints between two chips or chips to package [4], while the embedding solder provides still some ductibility of the composite joints.

As shown on Fig.2, CNF wets some solders remarkably well leaving hardly any voids at the fiber/CNF interface, forming a composite joint with lower CTE that the solder itself, since VACNF have hardly any CTE. Further, the wetability of the CNF to the solder could prevent the solder from wicking out and away from the pads, thus reducing the number of solder shorts that occur as the solder pad-pad pitch gets smaller.

The length of the rooted CNF is solely determined by the CVD growth process. Fibers as long as tens of micrometers are routinely grown. Such length make it possible to enhanced the reliability of the fiber to solder joint, since fibers could be longer than the intermetallic region on the solder to pad interface.

All the above features of the CNF/solder composites make them very promising for Nano-scale interconnects with improved reliability. In a study conducted by Ho and Chung found an 87% increase in thermal fatigue life by creating a 29% by volume mixture of CNFs and solder [2].

Summary

As solder joints get smaller their reliability and fatigue life drops. Adding carbon nano fibers and combining with the solder significantly enhances the fatigue life of the solder joints.

References

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