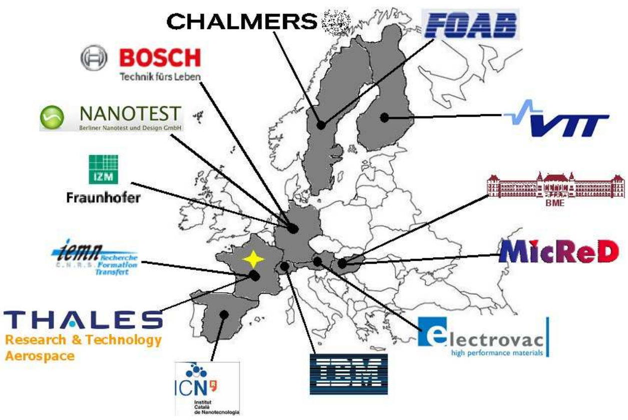
Nano Packaging Technology for Interconnect and Heat Dissipation

December 2008 **Newsletter #2**

NANOPACK is a European large-scale integrating project aiming at the development of new technologies and materials for low thermal resistance interfaces and electrical interconnects, by exploring the capabilities offered by nanotechnologies, such as, carbon nanotubes, nanoparticles and nano-structured surfaces, and by using different mechanisms to enhance interparticle contact formation, combined with high volume compatible manufacturing technologies. Several key research areas relative to thermal management interconnects and packaging are addressed by European industrial and academic partners: thermal interface materials, assembly, reliability and characterisation; supported by world class modeling and simulations. The benefits of the technologies will be evaluated in different applications to demonstrate improved performance of microprocessors, automotive and aerospace high-power electronics and radio-frequency switches.

Presentation of the NANOPACK Consortium

The NANOPACK consortium consists of 4 major industrial partners (Bosch, IBM, Thales Aerospace and Thales Research and Technology), 4 innovative SMEs (Foab Elektronik, MicReD, Electrovac, Berliner Nanotest und Design), and 6 academic groups (Budapest University of Technology and Economics, Fraunhofer Insititut IZM, Chalmers University of Technology, Catalan Institute of Nanotechnology, VTT Micro and Nanoelectronics, Institut d'Electronique de Microtechnologies et de Nanotechnologie) in total representing 8 European countries.



Progress in Material Developments

Specification of filler system and matrix system for nano-TIM development

As part of the deliverable D2.2, three matrix systems for adhesive Ag (nano and micro size), CNT/CNF and Graphite filler systems have been developed. The highest thermal conductivity, that has been demonstrated so far using epoxy-Ag bimodal system was 10W/mK. In addition, ceramic filler materials and filler systems, such as c-BN, SiC and AlN have been also studied. Matrix systems like curable/non-curable, screen printable, silicon/siliconfree, metal/non-metal and organic phase change materials (PCM) have been considered for developing grease, adhesive and nano-enhanced PCM. Samples of adhesives, greases and CNF enhanced PCM have been fabricated using different fillers, filler systems and matrices. The performance evaluation of the delivered samples is in progress.

Nano-structured materials for nano-TIMs and interconnects

The deliverable D2.3 “Nano-structured materials for nano-TIMs and interconnections“ addressed the production of various nano-structures materials for thermal and interconnect issues:

A technology concerning nano-Ag coating on CNF/CNT has been developed by dispersing and functionalizing CNF/CNT followed by Ag precipitation. A series of experimental steps dealt with the preparation of bulk CNF. These steps include preparing and pre-treating a catalyst precursor; reducing and activating the catalytic nano-particles; growing CNFs by CCVD and finally characterising the CNFs. The CNF was graphitized at 3000℃ to reach high thermal conductivity followed by fabricating TIM using the newly developed CNFs as the filler material. In addition, Multi-walled CNTs (MWCNT) and single-walled CNT (SWCNT) have also been grown by PECVD and by TCVD respectively. The length of the SWCNT was controlled by the duration of the growth to reach 50 to 100 µm. But only one third of the fabricated SWCNT were metallic and then likely to have a very high thermal conductivity. On the other hand, the MWCNT are all metallic but won’t be longer than 15 µm after optimization of the PECVD process.

Nanofibrous polymer substrates have been successfully fabricated and results have been presented at two conferences and submitted to one scientific journal. Fabrication technologies based on three different polymer systems have been studied. Technologies are developed and demonstrated in final application for thermoplastic polyurethane elastomer (TPU). Successful samples have been demonstrated for thermoplastic polyimide (PI) and technology is under development for thermoplastic polyether-block-amide elastomer (PEBA).

Gold nanograss has been developed by electrochemical deposition (ECD) on 8 inch wafer substrates for TIM and interconnection. Use of nanoporous templates as a plating mask for the growth of nanoscale mono-metal structures is in progress. After sintering of this layer, a high thermal conductive TIM-layer is possible. From the literature review, it is clear that all processes based on self-assembly of copolymers are not suited for nano-porous templates with the properties needed, as hole diameters are well below 100 nm and resulting layer thickness is also limited to the same range, yielding structure heights not considered useful for larger IC bonding due to coplanarity reasons. The processes using nano-lithography/RIE-structuring are suitable as a “ready-to-use” solution for nano-porous templates and are being developed.

The aim of developing CNT mats and bucky paper is to realize a thermal interface based on vertically aligned carbon nanotubes. The final interface will be processed by the assembly of a CNT mat deposited on the die to be cooled and a dense array of oriented CNTs grown on the superior surface of the interface, the whole infiltrated by an adapted matrix to enhance thermal and mechanical properties. Surface functionalization of substrate for nanotube adhesion has been developed. The use of a small molecule instead of a polymer addresses the issue of the thermal contact between the substrate and the CNT. The achievement of such structure is summarized in a technical report.

Nano-filler based thermal grease with high thermal conductivity and low thermal resistance

The investigation of nano-filler based greases has been carried up to now in four stages as presented in the deliverable D2.4. In the first stage, graphitized carbon nanofibers and CNFs/CNTs have been systematically studied in different matrices. A new matrix system has been found to provide a better wettability and incorporation with CNFs. Dispersion parameters were optimized to allow uniform embedding of CNF in the matrix. the thermal conductivity has been improved by introducing micro-fillers to nano-filler system. The new thermal grease formulation comprises of graphitized CNFs and micro-sized graphite particles. A thermal conductivity of 2.88W/mK has been measured which leads to low thermal resistances of 12.25 Kmm^2/W for BLT<35µm and 3.5Kmm^2/W for BLT<10µm, respectively. Finally, formulation of nano-microfiller combined grease and manufacture process have been optimized so that a thermal conductivity of 4.45 W/mK has been reached.

Nano-filler based thermally conductive phase change materials

Phase change material (PCM) shows thermal storage capacity due to its latent heat of transformation, but its low thermal conductivity limits its application in transient thermal management of larger systems. In order to improve the thermal performance, high thermally conductive CNFs/CNTs are incorporated into PCM. It is expected that the use of the graphitized carbon nanofiber will improve the thermal performance and lower the operating temperature of the system. It has been reported[1] that dry CNT arrays show a thermal resistance of at least 19.8 mm^2K/W, while the combination of a CNT array and a phase change material shows resistance of at least 5.2 mm^2K/W. We have started to investigate nanofiller reinforced thermally conductive PCM. First results are presented as milestone M2.3, including the selection of phase change material (PCM), optimisation of CNF dispersion into PCM, uniformity evaluation of CNF in PCM, measurement of thermal resistance and the dependence of thermal resistance on mixing time.

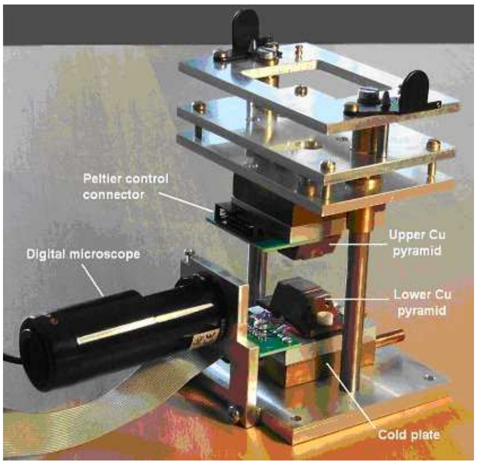
Process Development and Optimisation

First demonstration of successfully modified surfaces for thermal interfaces

Hierarchically nested channel (HNC) technology uses channels in the thermal interface between two solids. It was developed at IBM to reduce the thermal resistance of an electronic package and has been demonstrated with interfacial areas ranging 1-250 cm^2. This surface modification technology allows lower operating temperatures and/or higher power and shows promise for automotive, power electronics, optical, RF, and microprocessor applications.The milestone M3.1 "First demonstration of successfully modified surfaces for thermal interfaces" has been completed as an interim step toward a future deliverable. This deliverable will present additional approaches including nano-enhanced surface structuring and growth of carbon nanotude (CNT) arrays on heat spreader surfaces to augment heat transfer through the interface. These technologies may all be complementary since CNT and nano-enhanced surfaces are likely compatible with the HNC technology. The final optimized surface-enhancement will likely be a tradeoff in the relative contribution of each surface approach and manufacturing and cost considerations.

Design and Fabrication of Test Systems

First designs of intelligent test chip, thin film heaters and assembled test systems for characterisation



Three types of test systems have been designed through the milestone M4.1 and are briefly presented here:

- A 3-omega setup has been designed and is under construction to measure the thermal conductivity of samples produced at room temperature. A future update of the experiment will incorporate a cryostat enabling measurements of thermal properties in the range 8 – 500K.
- A static TIM tester is also under construction. The basic idea of the design is to use the micromachining facility provided by the recent technology of integrated circuits. In this way the realization of very small sized sample holders becomes possible, with temperature sensors positioned in extreme tight vicinity of the investigated TIM layer. A Rth resolution of 0,03 Kmm^2/W is expected for nominal measurements as low as 2 to 5 Kmm^2/W.
- Test System for mono-metal TIMs: The idea of this test system is to measure the thermal conductivity of very highly conductive metal-based TIMs with the help of a steady state technique. Solders as well as sintered mono-metal layers could be tested with this method, which should yield good results up to thermal conductivities of 100 W/mK within an accuracy of < 10 %. The advantage is that the thermal conductivity is measured under processing conditions as in real applications.

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[1] Xu et al., *Enhancement of thermal interface materials with carbon nanotube arrays*, International journal of heat and mass transfer , 2006, vol. 49, no9-10, pp. 1658-1666

Modeling and Simulations

Heat transfer within and between thin film systems and potential mechanisms to increase spreading investigated by Molecular Dynamics

Important aspects related to the prediction and enhancement of thermal properties, such as, thermal conductivity, conductance and thermal resistance using molecular dynamics simulations in thin film systems, including solid-liquid and solid-solid interfaces have been investigated by Molecular Dynamics Simulations. All aspects discussed on the deliverable D6.1 are directly connected with materials used as thermal interface materials in Nanopack, which might be of interest to a broad audience. A lot of care is taken to describe those materials that can be realistically studied using the method cited. Two cases are presented to show the importance of molecular dynamics modeling on the identification of mechanisms to increase heat dissipation.

First results from packed particle model with twice enhanced conductivity

FEM models have been developed to investigate thermal properties of random and ordered packed particle formations with comparison to percolation models. A cubic cell model has been established to evaluate the effective thermal conductivity of the thermal conductive adhesive (TCA) consisting of a polymer matrix and conductive fillers. This model has been applied to the Ag filler in epoxy matrix. Primary results show that a thermal conductivity of 20W/mk can be reached.

First results for phonons from particles on SOI surface

The main objective of milestone M6.2 was to build new numerical tools, based on FDTD method, to calculate the phonon dispersion relations and transport in structures constituted by a membrane supporting an array of particles. For periodical array of cylindrical dots deposited on a thin plate, the phonon band structure displays a low frequency gap that persists for various combinations of the materials constituting (plate and dots) and is associated with resonant modes of the individual dots. In addition, the transmission spectrum of normally incident phonons was calculated between two substrates through a periodic set of particles. The calculated spectrum shows fast oscillations and gaps, related to the periodicity of the structure, materials used, and dimensions of dots.
Current investigations are dealing with the effect of many physical parameters involved in the phonon transmission problem associated to Nanopack TIMs, for instance: particle shape, coating materials, embedding of the particles with different background materials (e.g. PDMS or epoxies), etc. New numerical tools are also under consideration to study the phonon transmission in the direction parallel to the membrane. To enhance the possibility of numerical calculations which are time consuming in FDTD method, some works are in progress to parallelize the existing programs to solve the finite difference equations in different regions of space. All programs developed are available to other Nanopack participants.

Remember to visit us at:
http://www.nanopack.org/

NANOPACK is a project co-funded by the European Commission under the "Information and Communication Technologies" Seventh Framework Programme Grant Agreement n°216176

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