MECHANICAL AND THERMAL PERFORMANCES OF CNT MICRO-PIN-FIN COOLER WITH AIR JET IMPINGEMENT

Yan Zhang[*a)] & Jing-yu Fan[**]

[*]*SMIT Center, Key Laboratory of Advanced Display and System Applications, Ministry of Education & School of Mechatronics Engineering and Automation, Shanghai University, Shanghai 200072, China*

[**]*Shanghai Institute of Applied Mathematics and Mechanics, Shanghai University, Shanghai 200072, China*

Summary Micro-cooler has been considered as one of the promising cooling schemes for high-powered electronic devices. Micro-pin-fin made of carbon nanotube (CNT) is a potential micro-cooler for on-chip thermal management. In the present work, the mechanical and thermal performances of the CNT micro-pin-fin cooler with air jet impingement is experimentally tested and numerically simulated, and the influencing factors of the micro-pin-fin cooler, such as fin geometry and jet flow features, are further analyzed.

INTRODUCTION

The ever-increasing power consumption of electronics coupled with the shrinking dimensions of devices makes the thermal management becoming critical in the design and packaging of electronic products. Micro-scale cooling techniques have drawn more and more attention for dissipating heat from small areas, and micro-channel cooler, which was first described by Tuckerman[1], is an efficient heat-exchange heat sink designed for devices with high power densities and has been widely discussed in numerous applications in electronic products because of its simple construction, fabrication process and highly efficient heat transfer level [2][3]. Micro-pin-fin heat sink is an effective alternative to micro-channel cooler that provides integral cooling to electronics or microelectromechanical systems. Carbon nanotube (CNT), at the same time, is becoming a promising material in micro-coolers due to its superior properties, and micro-fin structure made of aligned multiwalled CNT arrays was achieved [4]. The CNT micro-pin-fin cooler with air jet impingement can further provide an effective localized heat removal capability and then be applied as a powerful solution to high heat fluxes in discrete heating chips. In the present paper, the functional reliability of the CNT micro-pin-fin cooler with the air jet impingement is experimentally studied, and the numerical simulation is also carried out on the thermal performance of the micro-pin-fin cooler with various pin-fin and jet parameters.

EXPERIMENTAL INVESTIGATION

Experimental setup and samples

In order to test the reliability of the CNT fins, a set of experimental system is set up, and the sketch map of the impinging jet experiment is shown in Fig. 1. The jet nozzle size d is of 1.4mm and 1.8mm in its inner and outer diameters. The distance from the jet nozzle to the fins h and the jet nozzle velocity/flux can be adjusted.

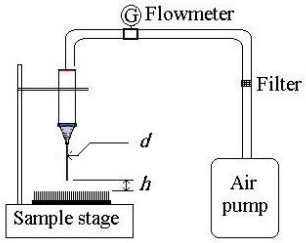


Fig. 1 Sketch map of the impinging jet experiment

The CNT fins are fabricated on 6×6 mm silicon substrates with about 100μm in diameter and 200μm in pitch, and the height are of approximately 100μm. Two kinds of CNT pin fin configurations are tested when considering the reliability, as shown in Fig. 2. In one case the fins are located around the substrate perimeter, and in the other case the fins are uniformly distributed in the central area of the substrate. In both cases, the outline of the CNT is 4×4mm. During the jet impingement experiment, the sample is fixed on the sample stage and then exposed to the impingment of an air jet. The jet is located above the central point of the sample, and the distance from the jet nozzle to the fin tip is 8mm.

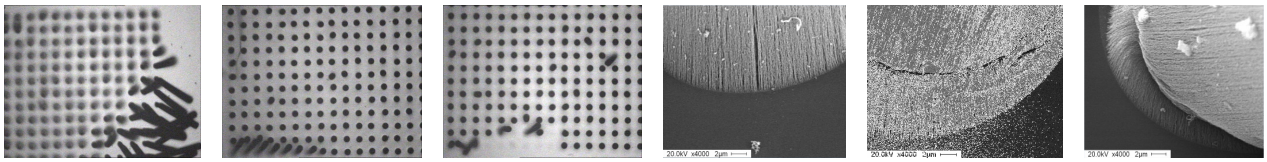
(a) Peripheral distribution (b) Central area distribution

Fig. 2 Sketch and photo of the CNT pin-fin samples

[a)] Corresponding author. Email: yzhang@shu.edu.cn.

Results and analyses

The samples are subjected to the air jet impingement with different jet nozzle fluxes for 30 minutes. Under all the experimental conditions, no significant damege is observed on the samples with the peripheral CNT micro-pin-fin. For the samples with the CNT fins uniformly distributed in the centeral area, it is the corner regions instead of the center part where the CNT fin deformations appear. Fig. 3(a) and Fig. 3(b) show the sample's upper right corner and lower left corner, respectively, and the fins near the boundary outlines are destroyed more seriously. And in some cases, as shown in Fig. 3(c), the fins are even blown away from the silicon surface. Fig. 3(d)-(e) give the enlarged photos of the CNT fins. It can be inferred that the damage originates from the root of the fins.



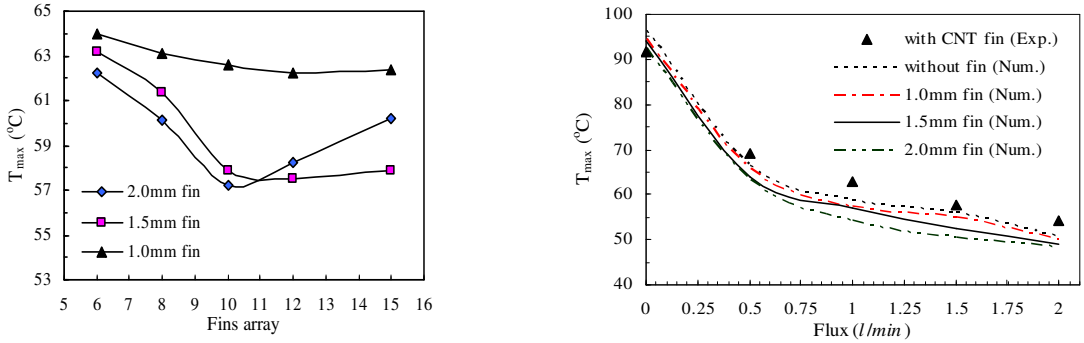
(a) (b) (c) (d) (e) (f)

Fig. 3 Photos of CNT fins after jet impingement

NUMERICAL SIMULATION

When packaging a chip with the micro-cooler, there are many constraints that must be considered. In addition to the reliability observation of the CNT micro-pin-fin cooler, the numerical simulation on the thermal performance of the pin-fin cooler with different configurations is carried out. Three-dimensional computational fluid dynamics (CFD) model is developed for the micro-pin-fin coolers, and the characteristic parameters of the pin-fin including fin array, fin high as well as the impinging jet features are analyzed. The junction temperature of component or device is the main parameter when evaluating micro-cooler performance, and the maximum temperature is chosen in the following analysis.

As shown in Fig. 4(a), the fin array of 10×10 is the most optimal one for the cases considered. With the increasing jet nozzle flux, the T_{max} decreases obviously and this corresponds to better heat dissipation. However, in Fig. 4(b) it can be seen that the jet flux does not exhibit an appreciable influence on the highest temperature of the micro-pin-fin cooler with different fin heights. The reason is likely to be that the jet nozzle is mounted at a distance of 8-10 times of the fin height above the cooler, and thus the air jet mainbody has expanded horizontally before it reaches the fin array.



(a) Fin size and number vs. T_{max} (b) Air jet flux vs. T_{max}

Fig. 4 Effect of micro-pin-fin parameters on maximum temperature

CONCLUSIONS

In this paper, the reliability of the CNT micro-pin-fin with air jet impingement is experimentally investigated. Samples with the CNT pin-fin distributed peripherally and bestrewed over the substrate area are tested, where the former shows fairly good strength and the latter exhibits no obvious deformation in the central region but local damage in the boundary parts. In addition, the numerical simulation is carried out on the thermal performance of the micro-pin-fin cooler with different fin array, fin size and jet features. The obtained results can provide guide for optimization in future design and application.

Acknowledgments The work was supported by the National Natural Science Foundation of China (10702037). Supports by Innovation Program of Shanghai Municipal Education Commission (12YZ006, 12ZZ083) were also appreciated.

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