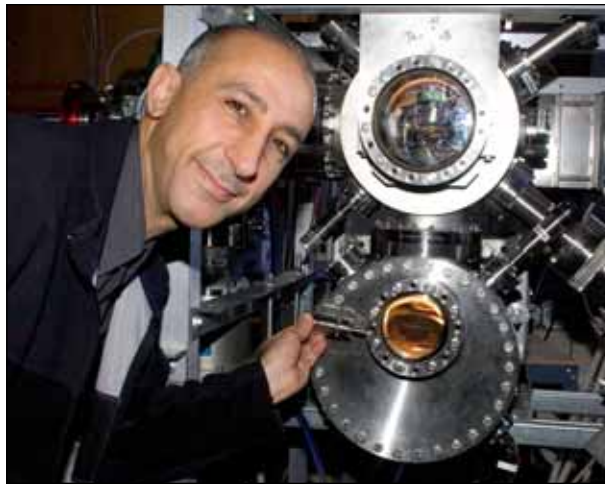


Micro Column Arrays (MCA) for Thermal Management of Spacecraft Environments

Abdelhak Bensaoula

Abstract—Investigation of Micro Column Arrays (MCA) for thermal management of spacecraft environments has been continued in conjunction with a project employing a Post-Doctoral Aerospace Fellow on diverse thermal management applications. Finite element method (FEM) simulation of MCA structures has been used to study the influence of MCA aspect ratios on heat loss.

EXPLORATION OF SPACE CALLS for adaptations of manned vehicles to ensure the comfort and survival of passengers and crew. Unmanned exploration is also concerned with the integrity and durability of spacecraft. Reducing heat generated by spacecraft components requires a strategy no less than the need to heat spacecraft systems. Conventionally, liquid-based heat exchangers are employed for this purpose. Thermal systems increase the weight of space vehicles and contain parts that may malfunction. Researchers seek to reduce the weight of thermal systems and simplify their mechanics to ensure longer periods of flight in space.



Dr. Abdelhak Bensaoula

We have developed a technology for the successful fabrication of Micro Column Arrays (MCA) on thin metal foils in conjunction with Integrated Micro Sensors, Inc. (IMS) of Houston, TX. Micro Column Arrays consist of densely packed micro cones separated by cone-shaped micro cavities and exhibit low reflectance (<0.171) and high absorbance (>0.978) over a wide spectral range in a very close approximation of blackbody behavior. The project seeks to explore MCA structures from thin foils as a possible passive cooling system which would collect or remove heat by radiative absorption or emission through their near-blackbody nature.

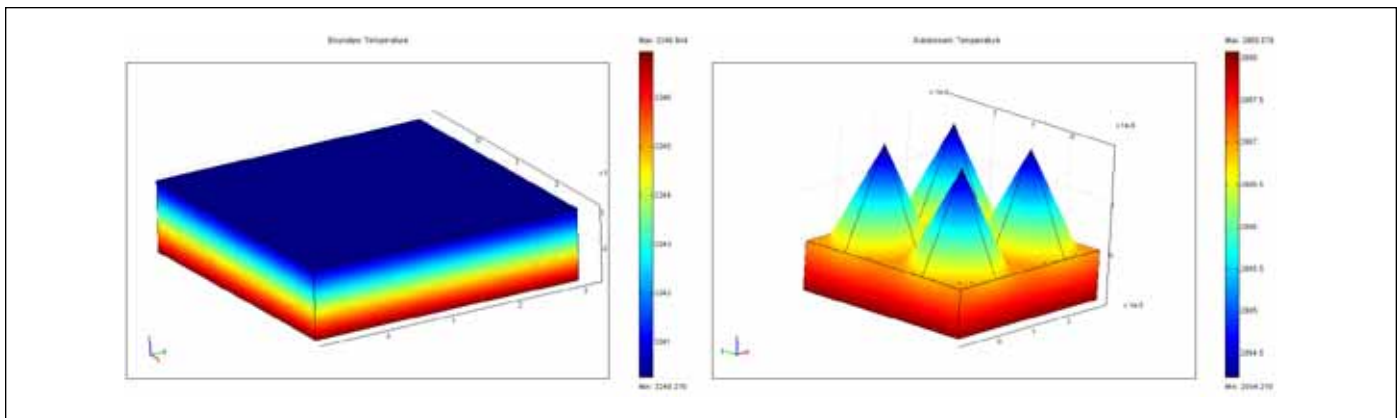


Figure 1. Finite element method simulation of the steady state temperature under a constant heat flux ($5 \times 10^6 \text{ W/m}^2$) for (a) un-structured and (b) MCA-structured silicon carbide. The MCA sample has a 13.5% lower temperature.

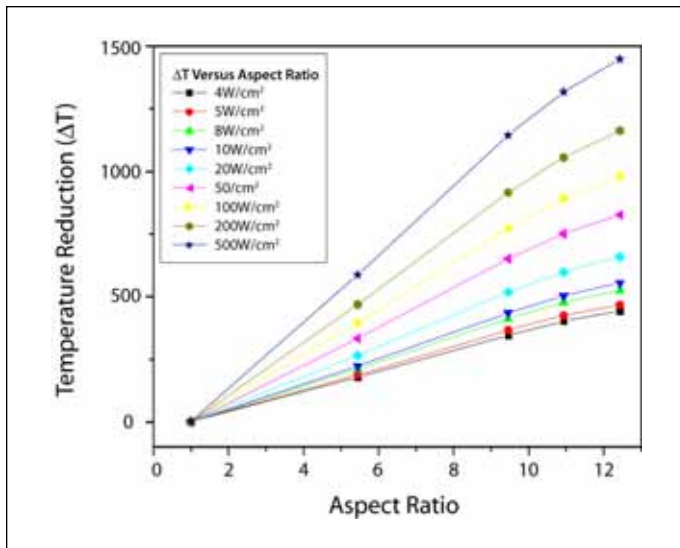


Figure 2. Simulations carried out on the MCA model of different aspect ratios on *Ti*, showing temperature reduction of the base for a wide range of heat fluxes at different aspect ratios. Saturation due to surface-to-surface radiation occurs for an aspect ratio ~12.

We undertook computer simulation of MCA thermal properties to better understand the effect of MCA geometry on heat loss properties. Thermal analysis was carried out using Comsol FemLab 1 software, which has a feature that applies a finite element method (FEM) for solving complex multi-physics problems, including heat transfer due to conduction, convection, and radiation. This analysis allowed us to investigate the influence of MCA geometry on the resulting heat loss—in particular the aspect ratios.

Results

Initial FEM modeling indicated that MCA are very effective heat reducers compared to smooth metal surfaces. Shown in Fig. 1 is a FEM analysis of the temperature under a fixed heat flux of bare *SiC* and a *SiC* MCA. A 13.5% reduction in temperature was realized. In space applications, payload volume and weight are important design parameters. From that perspective, *Ti* has the lowest density (4.5 g/cm³) when compared to other materials from which we have made MCA, such as Tantalum (16.4 g/cm³), Hastelloy C276 (8.94 g/cm³), and Alloy321 (7.92 g/cm³). Additionally, *Ti* is more stable in space and extreme environments than other lightweight metals such as Aluminum. As a result, we have used *Ti* as the base material for further FEM analysis.



COATINGS—A multi-element coating reactor for hardcoating MCA structures in the Center for Advanced Materials. Such state-of-the-art equipment allows new technologies providing for the successful fabrication of micro-column arrays. Researchers are led by Dr. Abdelhak Bensaoula.

For a given density of the MCA, the crucial simulation parameter which determines the amount of heat loss is the aspect ratio of the structures. This can be defined as the ratio of the total extended surface area to the base area. Since heat loss through radiation is proportional to the area of the emitting surface, a large aspect ratio leads to increased heat loss from the MCA. At high aspect ratios, however, the increased surface area is offset by increased surface-to-surface radiation between individual columns. This is illustrated by Fig. 2, which shows the temperature of titanium MCA with different aspect ratios for a variety of heat fluxes. The saturation of the heat loss begins near an aspect ratio of 12. This knowledge will allow us to predict the heat loss behavior of the MCA so that we can tailor the structures for different applications in addition to providing optimal geometry information to refine the MCA formation process.

Funding and Proposals

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