Heat Removal of Microelectronics through Plasma Technology

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Abstract:

Rotary fan technology is an inadequate cooling method of microelectronics and does not meet existing technology needs. Electrostatic fluid accelerators (EFAs) have been proven as a promising alternative cooling technology, but break down due to electrode degradation. To increase EFA lifetime, longevity tests were conducted in order to identify electrode erosion. Conductive inert chemicals were investigated as coating materials to increase electrode longevity.

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Introduction:

Existing thermal management methods for electronics do not meet technology needs and remain a major bottleneck in the evolution of computing, sensing, and information technology. The decreasing size of microelectronics components and the increasing thermal output density require a dramatic increase of thermal exchange surface.

In standard cooling technology, heat sinks are used for thermal management of microelectronics. As a result of increasing component density, heat sinks become denser and the channels become narrower. This causes gases to be viscous which decreases cooling efficiency. Traditional rotary fan technology has reached its limit in size reduction. It requires large surface and high speed moving parts causing noise and vibrations.

Electrostatic fluid accelerators offer numerous benefits over the heat sink-rotary fan technology. Advantages include no moving parts, nearly silent operation and no vibration effects. EFAs create laminar airflow with controllable velocities, which increases heat transfer performance. EFA technology is also not limited by geometry, shape or size.

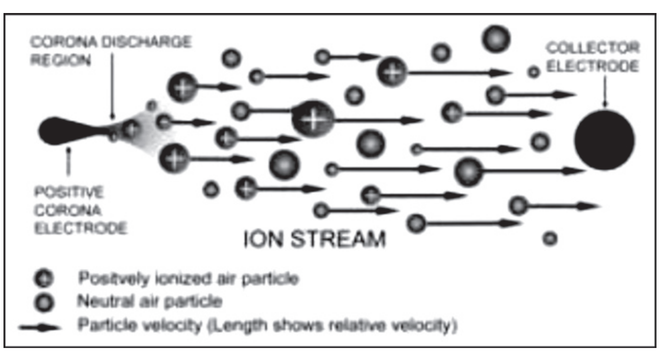

Figure 1: Corona wind from EFA operation.

Figure 1 shows a schematic diagram of ion stream generating from a DC electrohydrodynamic ionic wind pump [1]. This mechanism uses a pin-rod geometry with a high tip-curvature corona electrode and a low tip-curvature collecting electrode. Application of a high electric potential difference between the electrodes results in a high intensity electric field in the vicinity of the corona electrode tip, ionizing the surrounding air molecules. These ionized air molecules, which are propelled by the electric field, transfer part of their kinetic energy to neutral air molecules via collisions and create airflow called corona wind.

Electrode degradation results in the break down of an electrostatic fluid accelerator. Electron collisions with the major constituents of gas (O_2, N_2, H_2O) produce relatively high densities of reactive species such as O, N, and OH. In addition, columbic forces acting on these molecules lead to their sedimentation on the electrodes [2]. The material of the corona electrode influences ozone generated by corona discharge because the material affects the current-voltage characteristic in air [3]. Electrodes can become contaminated by deposition of products from chemical reactions in the corona plasma, deposition of air-borne particles and surface oxidation.

Experimental Procedure:

Microfabricated atomic force microscopy (AFM)-cantilever corona electrodes were fabricated from silicon wafers using a three-step photolithography procedure: cantilever structure patterning, corona tip patterning and corona tip shaft patterning. An isotropic reactive ion etching process was used for corona tip sharpening and an anisotropic deep reactive ion etching process was used for high aspect ration tip shaft formation. Figure 2 shows the schematic diagram of the EFA configuration for EFA-enhanced forced convection cooling. For current-time testing, the microfabricated AFM-

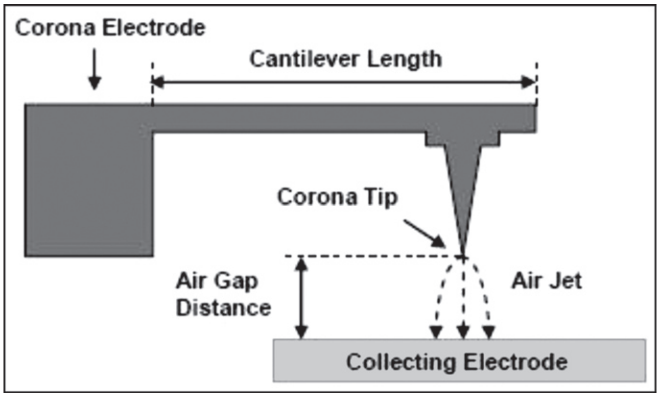

Figure 2: Concept diagram of configuration for EFA-enhanced forced convection cooling

cantilever corona electrodes were suspended 5 mm over a flat collecting electrode in ambient air conditions of 22°C. During operation, 5 kV of positive DC voltage was applied to the corona electrodes.

Uncoated, titanium-tungsten coated and platinum-coated microfabricated AFM-cantilever corona electrodes were tested for the investigation. Unsharpened electrodes were used for the testing because of ease of experimental analysis. Scanning electron microscope (SEM) and energy-dispersive x-ray spectroscopy (EDX) were used to image the degradation and analyze the electrode erosion.

Results:

Corona current trends for uncoated silicon corona electrodes showed a stable current for hour 1. Current peaks resulted from streamers in hours 2 and 3. The overall trend decreased over time. Pt-coated and TiW-coated electrodes produced a constant current for all three hours with no streamers. Uncoated corona current trends indicated that the electrode surface changed. This effected the electric field distribution, which caused streamers resulting in high current peaks. Dust attachment, material deposition or oxidation can cause surface change.

Experimental results verified that the electrode erosion was caused by oxidation. Materials coating corona electrodes demonstrated chemical inertness. Chemical analysis and imaging before and after tests showed significant reduction in oxidation and electrode corrosion. Titanium-tungsten and platinum materials proved to increase corona electrode longevity.

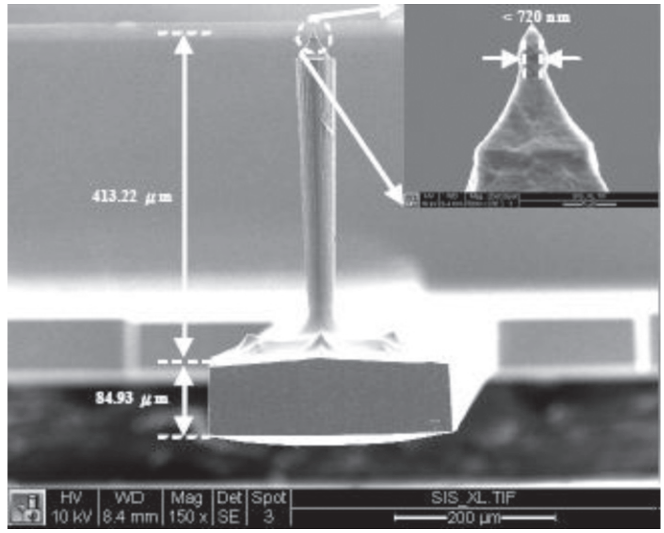

Figure 3: SEM image of microfabricated AFM-cantilever corona electrode.

Future work includes further miniaturization of electrostatic fluid accelerators for integration into chip structures. Also, additional longevity testing will show the EFA break down point for Pt-coated and TiW-coated electrodes.

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References:

[1] C.P. Hsu, N.E.. Jewell-Larsen, C. Sticht, A. Mamishev, "Heat Transfer Enhancement Measurement for Microfabricated Electrostatic Fluid Accelerators," Department of Electrical Engineering, University of Washington, 2008.

[2] L M. Dong, S. Ian, J. X. Yang, X. C. Chi, "Plasma chemical reaction for nitric oxide and sulfur dioxide removal in corona discharge reactor," 2003 Annual Report, Conference on Electrical Insulation and Dielectric Phenomena, Harbm University of Science and Technology, China.

[3] A. Yehia , A. Mizuno, "Silver discharge electrode for suppression of ozone generation in positive dc corona," Department of Physics, Faculty of Science, Assiut University, Egypt.