Cold atmospheric plasma assisted selective annealing of gold nanoparticles

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Abstract: In this work, we report selective area annealing of gold nanoparticles (AuNP) using a cold atmospheric pressure plasma (CAPP) jet. The AuNP films are deposited on silicon and polyimide substrate using the plasma spray technique. The AuNP films are treated with a CAPP jet for 5-15 mins. The significant arcing observed during plasma processing results in the sintering of nanoparticles, which enhances the conductivity of the film.

1. Introduction

Annealing of metal nanoparticles is the essential process for improving their structural integrity and enhancing their physical properties. The nanoparticle films can be optimized for various applications, including electronics, sensors, and catalysis, by controlling the temperature and environment during the annealing process. The current nanoparticle annealing techniques, such as thermal, laser, and microwave annealing, offer flexibility in achieving the required goals, such as crystallization, defect reduction, or controlled particle growth. However, one of the significant problems with these techniques is the elevated substrate and film temperature (up to a few hundred °C), which limits their use only to solid substrates. This work investigates the low-temperature plasma-assisted deposition and annealing of metal nanoparticle films on flexible substrates such as polyimide, paper, and fabric at room temperature. The studies are carried out to understand the effect of plasma processing time on the morphology and conductivity of the gold nanoparticle (AuNP) films. Surface energy measurements are ongoing and will be reported later.

2. Methods

The atmospheric plasma jet is created by passing the argon gas through the quarter-inch diameter quartz tube and applying high-frequency (~30 kHz) and high-voltage (10 kV) to the two copper electrodes placed on the quartz tube. A gold nanoparticle mist (mean diameter of 20 nm) is created by ultrasonic excitation, which is carried to the plasma region of the cold atmospheric plasma jet. The nanoparticles interact with the plasma and get deposited on the substrate. The detailed deposition process is explained in our previous works [1, 2]. The plasma jet-nanoparticle dispenser assembly is mounted on the x-y arm to deposit 1.0 cm x 0.2 cm lines of AuNP films on silicon, quarts, polyimide, paper, and textile substrates. As deposited, nanoparticle films are further treated with atmospheric plasma for 5, 10, and 15 minutes in the same assembly by turning off the nanoparticle particle dispenser. Scanning Electron Microscopy (SEM), Atomic Force Microscopy (AFM), and four-point probe measurement techniques are used to study the morphology, surface features, and conductivity of the AuNP thin films.

3. Results and Discussion

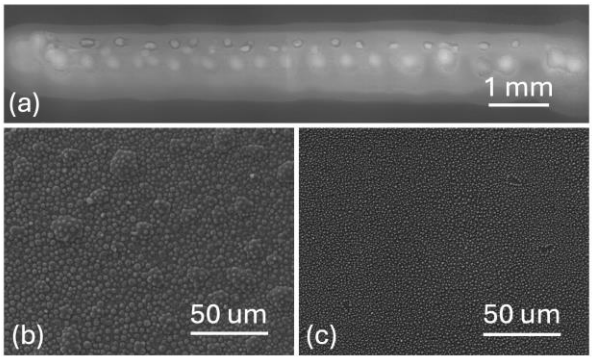

Fig. 1. SEM images of AuNP films deposited on a silicon. (a) entire 1 cm deposited line, (b) concentrated nanoparticles in region 1, seen as bright spots on the line, (c) region outside bright spots (region 2).

Figure 1 shows the SEM images of the AuNP films deposited on a silicon substrate. As seen, there are two distinct regions: the bright spots where the concentration of Au particles is higher (region 1) compared to region 2 elsewhere. In region 1, the diameter of particles is 100 nm to 2 μm. The particles are agglomerated in this region, covering the entire substrate. In region 2, the mean diameter of the particles is 200 nm, and particles are dispersed evenly on the substrate. It has also been observed that the mean diameter of the particles in region 2 increases with the plasma processing time. The conductivity of the processed samples increases with processing time, which is the maximum for the 15-minute processed sample. During the plasma processing, after 1 to 4 minutes, the plasma jet showed filamentary behavior with increased arcing.

4. Conclusion

The SEM images, conductivity measurements, and plasma jet observations demonstrate that the significant arcing in the plasma jet leads to selective sintering of nanoparticles, thereby increasing the conductivity of the AuNP thin films.

References

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