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Transport of nanoparticle cloud having a fractional elementary charge by amplitude modulating pulse discharges

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We have proposed a bottom-up nano-system fabrication method, which consist of production of nanoparticles as nanobuilding blocks and radicals as adhesives in reactive plasmas, transport of nanoparticles towards a substrate, and their arrangement on the substrate using pulse RF discharges with the amplitude modulation (AM) of the discharge voltage. For the method, control of the size of nanoparticles and their manipulation without their coagulation are important. Up to now, we have studied on particle growth kinetics in a particle size range from sub-nanometer to micrometer in low-pressure, high-frequency discharges employed for depositing Si thin films [1]. Based on the results, we have developed a method for controlling the size of nanoparticles [2] and have realized their rapid transport from their generation region towards a substrate by pulse RF discharges combined with AM [3,4]. Here we report a criterion for driving nanoparticles rapidly and discuss their transport mechanism.

To obtain information about transport of nanoparticles, we have observed their transport in pulse capacitively-coupled RF discharges both without and with an AM using a 2-dimensional laser-light scattering method described elsewhere [3,4]. Nanopraticles were formed in 13.56 MHz RF discharges of $Si(CH_3)_2(OCH_3)_2$diluted with Ar. Since density of nanoparticels surpasses positive ion density, 1-15% of nanoparticles have a negative elementary charge, -e, and the rest are neutral. Hence, their average charge is in the range -0.01e to -0.15e, namely a fractional elementary charge.

Nanoparticles transport in AM discharges is classified into two kinds: one is the rapid transport at a velocity more than 60cm/s during the modulation period and the other is the slow transport at a velocity of 3-5 cm/s after turning off discharges. Two important parameters for the rapid transport of nano-particles are the discharge voltage $V_{AM}$and the period dt of AM. The threshold dt value between the rapid and slow transport increases with the size of nanoparticles, probably because the larger nanoparticles have the slower response time due to their inertia. The characteristic response time of nanoparticles is evaluated as charge of the nanoparticles $Q_p$using the dust plasma frequency f_{pd}[5]. The threshold dt value between two transport modes is close to the inverse of $f_{pd}$for Q_p= -0.005e in a size region of 25nm to 35 nm, and that for Q_p= -0.01e in a size region of 40nm to 45nm. The response time for Q_p= -0.1e, which is close to the experimental $Q_p$values, is much shorter than the experimental threshold dt values. We need a more sophisticated model to predict qualitatively the threshold dt values.

A key of the transport is rapid redistribution of ion current in discharges due to rapid change of potential distribution during the AM. Just after the initiation of the modulation, electrostatic force drives negatively charged nanoparticles. Neutral nanoparticles turn into negatively charged ones due to their charge fluctuation during the AM. Once they pass through the presheath region near the powered electrode, where ion drag force towards the powered electrode pushes them to the substrate.

References

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