Modeling of the Synthesis and Transport of Nanoparticles in Processing Plasmas

K. De Bleecker[1], A. Bogaerts[1] and W.J. Goedheer[2]

[1]PLASMANT – Dept. of Chemistry, University of Antwerp (UA), Universiteitsplein 1, 2610 Wilrijk, Belgium
[2]FOM Institute for Plasma Physics 'Rijnhuizen', Assoc iation EURATOM-FOM, Nieuwegein, The Netherlands

Dust formation has been observed in many processing plasmas, where nanometer or micrometer sized dust grains appear as a result of chemical polymerization reactions in the gas phase or from plasma-surface interactions. Management and avoidance of the formation of these particles in the so-called dusty plasmas was initially the main concern. In the semiconductor industry, for example, dust is often deemed as a limiting factor which can drastically degrade the product quality and reduce the manufacturing yield when it is incorporated into the depositing layer. Notwithstanding the harmful aspects related to the formation of the dust, the presence of fine dust particles can also be very beneficial in certain material science applications, mainly due to their very small sizes (e.g. nanometer area), chemical composition or uniform size distribution. In the photovoltaic cell production the creation and inclusion of nanocrystalline silicon particles in the intrinsic layer of amorphous hydrogenated silicon (a-Si:H), can result in the production of a new material, i.e. polymorphous silicon (pm-Si:H). This material shows improved transport properties and stability against the light induced effect – thus making it a good candidate for use in high-efficiency solar cells.

In order to control the morphology, growth and transport of the particles in the above mentioned and future technological applications, a better understanding of the particle formation mechanisms and dynamics is needed. For this purpose we have developed a fully self-consistent 1D fluid model that investigates particle formation in chemically active low temperature radio-frequency plasmas, such as SiH_4 and C_2H_2. Although the behavior of particles in the micrometer-sized regime is relatively well understood, the transition of gas species to particles remains a complex process, which is still open for investigation. These earlier stages, known as nucleation and coagulation, are of specific interest in the current research. Besides investigation of the initial stage of particle generation, the second fast coagulation stage can be incorporated by using an aerosol dynamics model. Once the particles reach the nanometer area, they will quickly acquire a negative charge due to the collection of plasma ions and electrons. In addition to the calculation of the nanoparticle charging via the OML theory, the dust transport equation needs to be extended to include the extra forces experienced by the nanoparticles (e.g. the ion drag, the thermophoretic, and the neutral drag force). The competition between these different forces ultimately leads to the confinement of the particles in well-defined regions of the discharge.