A recent paradigm shift of semiconductor manufacturing is a transition from 2D to 3D architecture. 3D power scaling, arranging/orienting transistors vertically rather than horizontally, achieves the rapid density increase with no decrease in transistor size required. There are many impediments to fabrication of such 3D architecture devices in industry: process fluctuations, ultra-multilayer thin film deposition, and etching of ultra-high aspect ratio holes, and so forth. For faster development of ultra-precision nano-fabrication methods for 3D devices, relations among spatial profiles of plasma parameters, growth of nanoparticles in reactive plasma and properties of fabricated thin films must be clarified. Here, we study such relations in reactive plasma using two high speed cameras.

Experiments were performed using a capacitively-coupled RF discharge reactor [1]. A powered electrode with a diameter of 60 mm was set 6 mm above an grounded electrode with a diameter of 60 mm. TEOS (Si(OC2H5)3) and O2 gas were supplied to the reactor at a flow rate of 40 sccm and 180 sccm, diluted with Ar at a flow rate of 160 sccm. The total gas pressure was 6 Torr. The RF discharge power was 30W and frequency was 13.56 MHz for a discharge period of T on = 8 s. Here, \((r, z) = (0 \text{ mm}, 0 \text{ mm})\) was the center of surface of the powered electrode.

For obtaining information of nanoparticles, we applied a 2DLLS method [2]. For this method, a sheet beam of 532 nm laser light was irradiated to the area between the electrodes, and the light scattering intensity from the nanoparticles was measured with a high-speed camera (Photron, 1000fps). The LLS intensity is proportional to nanoparticle density \(n_p\) and the sixth power of size \(d_p\) \((n_p d_p^6)\) in the Rayleigh scattering regime. For the study of relations between growth of nanoparticles and plasma, we measured simultaneously both LLS intensity and emission intensity of Ar I \(\lambda=750.4 \text{ nm}\) with two high speed cameras.

Figure 1 shows the \(z\)-profiles of LLS intensity (red line) and emission intensity of Ar I \(750\text{nm}\) at \(r = 0 \text{ mm}\) and \(T_{\text{on}} = 7\text{s}\). Nanoparticles grow near the powered electrode and emission intensity of Ar I has two peaks located close to the powered and grounded electrodes. Figure 2 shows the time evolutions of LLS intensity and emission intensity of Ar I \(750\text{nm}\) at \((r, z) = (0, 2-3 \text{ mm})\) region. The emission intensity of Ar I increases drastically and immediately after turning on plasma, then it gradually decreases and becomes almost constant after 4 s. Nanoparticles grow slowly, then they grow rapidly during 2-5 s and saturate in about 5 s. In recent other our experiments, we have found relations between property of SiO2 thin film and the spatial profile of emission intensity of Ar I. We will discuss details in the conference. This work was partly supported by JSPF KAKENHI (Grant No. JP19K03809 and JP20H00142).

References