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Radical controlled plasma processes ~ Basic researches and innovations ~

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The top-down fabrication processing of films employing a plasma etching and a deposition has been the most important issue over two decades to enable ULSIs to increase the number of layers on a chip to the multilevel. Such plasma process technologies have huge impacts on the production of various kinds of devices. As the fabrication scale is now moving aggressively to even sub-10 nano-meter with introducing new materials. New challenges are being faced to fabricate nano-structures with three dimensions. Generally, in the reactive plasma processing, species produced in the plasma reach the surface of a substrate and cause the etching, the deposition and the surface modification through surface reactions. These reactions are characterized by the densities and energies of species incident on the surfaces. In order to realize the nano-scale plasma processing, important species for plasma processing have been identified and characterized, and their behaviors, not only in the gas phase, but also on the surface, are clarified and precisely controlled. Especially, it is well-known that radicals play important roles in reactive plasma processes. We have proposed, therefore, the smart plasma nano-processing with radical controlling.

In this article, I will introduce three approaches towards radical controlled plasma processes with top-down, bottom-up and programmed processing methods. One approach to realize the smart plasma process, that is, a top-down method is the precise fabrication of nano-scale structures by controlling internal parameters directly during the plasma processing. For example, the plasma etching process is controlled with a real time based on the information of species and the substrate temperature monitored *in-situ*. To demonstrate it, the etching process of the organic low-k film was investigated in high-density plasma excited at a 100MHz using N_2/H_2 gas chemistry. The absolute H and N radical densities were measured by vacuum ultraviolet absorption (VUV) spectroscopy.

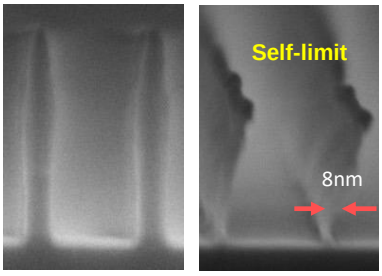

Fig. 1. The organic film pattern with 8 nm in size was etched by the radical controlled plasma processing with keeping a substrate temperature constant at 100℃. The left figure shows the as-etched pattern and the right one shows the pattern after the radical controlled trimming process.[1]

The pattern was etched and then trimmed by controlling the radical and the substrate temperature during the process. As a result, the vertical profile of 8 nm was fabricated at the radical density ratio of H/H+N=0.52 and a substrate temperature of 100℃ as shown in Fig. 1.

Secondly, the bottom-up nano-processes have become very important for the next generation's plasma processing. The three-dimensional carbon nano-structures, that is, Carbon Nano-walls (CNWs) have been synthesized with the bottom-up process in a novel plasma enhanced chemical deposition (PECVD) system with a radical controlled technique.[2] The carbon source gas of C_2F_6 was introduced into the rf capacitively coupled plasma region where a large amount of H radical was injected from outside. In the radical-controlled PECVD system, CNWs were successfully grown on various kinds of substrate without any catalyst. The radicals in the plasma were measured by VUV and appearance mass spectroscopy. Consequently, H and CF_3 radicals were found to play important roles for forming CNWs as shown in Fig. 2. By controlling these radicals, the width, the space and the height of CNWs grown in the bottom-up processing were successfully controlled.

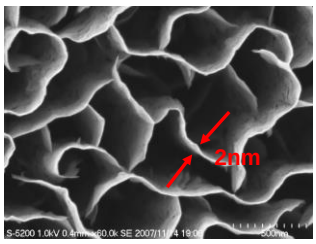

Fig. 2. CNWs were synthesized without any catalyst employing radical controlled plasma processing.[2]

Finally, it was found that the interaction of plasmas with liquid enabled to synthesize the plasma activated liquid, which causes cancer cells to kill selectively against normal ones through the apoptosis mechanism.[3, 4] The apoptosis is the programmed death, which is also one of the radical induced reactions in cells. We will discuss systematically the top-down, the bottom-up and the programmed processes induced by reactive plasmas, based on roles of radicals and their controls in plasma nano-processes towards driving of plasma innovations.

References

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