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Neutral Beam Technology for Future Nano-materials and Nano-devices

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I. INTRODUCTION

In the fabrication of semiconductor devices, reactive plasmas are widely used in key processes such as microfabrication, surface modification and film deposition, and there are now demands for processing precision at the atomic layer level, and for deposition accuracy that allows the control of structures at the molecular level. However, in ultra-miniature nanoscale devices that will become the mainstream in the future, the use of plasma processes can cause serious problems such as abnormal etching and breakdown of insulation films by the accumulation of ions or electrons emitted from the plasma , also the formation of surface defects (dangling bond) of over a few tens nm in depth by exposure to ultraviolet (UV) emissions from the plasma.[1-4] In particular, since nano-scale devices have a larger surface area compared with the bulk material, plasma processes can have a large influence on the electrical and optical properties of devices due to process-induced defects caused by ultraviolet exposure, since future nano-devices will require size control of three-dimensional structures at the atomic layer level, it will be absolutely essential to control surface chemical reactions with high precision and selectivity at the atomic layer level.

To achieve charge-free and UV photon irradiation damage-free processes, we have developed a new neutral beam generation system based on my discovery that neutral beams can be efficiently generated from the acceleration of negative ions produced in pulsed plasmas. This paper introduce the neutral beam generation technique[5] and discusses its application to atomic layer defect-free etching (ALE) , modification (ALM) and deposition (ALD) that have recently been pursued.

II. NEUTRAL BEAM SOURCE

Figure 1 is a conceptual illustration of the proposed neutral beam source, which has evolved from the pulse modulated plasma with an on/off switching time of 50 microseconds.[5] This source uses an inductively coupled plasma (ICP) source, and has carbon ion acceleration electrodes situated at the top and bottom of the quartz plasma chamber. Gas is introduced from the upper electrode in the form of a shower, and ions accelerated from the plasma pass through apertures (1 mm in diameter and 10 mm long) formed in the lower graphite carbon electrode, where they are neutralized by colliding with the aperture sidewalls. In a plasma modulated by pulses of 50 microseconds in duration, the electrons lose energy during the "off" periods, and undergo dissociative attachment with a halogen gas with a large electron affinity (chlorine, bromine or fluorine). As a result, an afterglow plasma during "off" period consisting of mainly both positive and negative ions is formed even in high density and low pressure plasma. We found that a neutral beam formed by the neutralization of mainly negative ions using a pulse-modulated plasma is able to form a neutral beam with higher density and lower energy than when using positive ions. We have already applied this technique to various state-of-the-art sub-25-nm devices, resulting in processes and device characteristics that have not hitherto been possible to achieve. [6-8]

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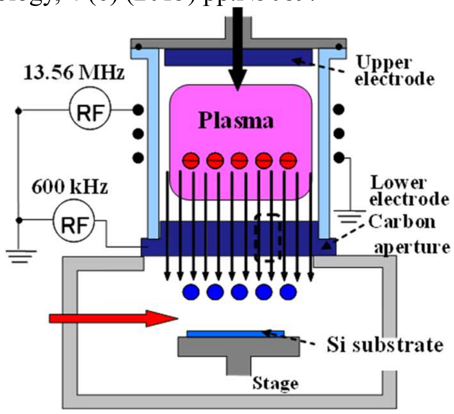

Figure 1. Neutral beam generation device developed based on new concepts. For the first time, we have achieved a practical neutralization rate and energy by using positive ions generated efficiently by pulse-modulated plasma.