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Ion energy control in capacitively coupled discharges for PEALD processes

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Damages on thin films and substrates, which are derived from discharges during deposition processes, are serious issues in semiconductor device manufacturing [1-3]. A solution to avoid them is controlling the ion energies of the discharges because these damages are attributed to high energetic ions in many cases. Here, ion energy control for capacitively coupled radio frequency (CCRF) discharges is demonstrated, and the applicability to plasma enhanced atomic layer deposition (PEALD) processes for synthesizing titanium (Ti) and titanium oxide (TiO_2) films is discussed [4-6]. The ion energy control is achieved by changing the impedance of one electrode (wafer stage) which consists of a tunable inductor and a constant capacitor, allowing us to modify the ion energy distributions (IEDs) at the wafer (see Fig. 1). For the TiO_2 process, the film characteristics show a clear correlation with the mean ion energy, $\langle \varepsilon_i \rangle$ i.e. the films become porous with a high $\langle \varepsilon_i \rangle$ whereas they do dense with a low $\langle \varepsilon_i \rangle$. Note that an excellent step-coverage of TiO_2 film deposited on amorphous carbon patterns has been obtained without any pattern deformation or damage on the films by tuning $\langle \varepsilon_i \rangle$ (see Fig. 2). For the Ti process, the growth per cycle of the films clearly increases with increasing, $\langle \varepsilon_i \rangle$, suggesting that increase in the ion energies of the discharges promotes the reduction process. Also, the film stress shows a clear dependence on $\langle \varepsilon_i \rangle$; it changes towards compressive with increasing $\langle \varepsilon_i \rangle$. On the other hand, the resistivity and the film density are almost constant independent of $\langle \varepsilon_i \rangle$, which indicates that the reduction reaction is saturated through the sequential PEALD cycles independent of $\langle \varepsilon_i \rangle$. In this presentation, the model to describe the film variations depending on $\langle \varepsilon_i \rangle$ is also introduced based on the experimental and simulation results.

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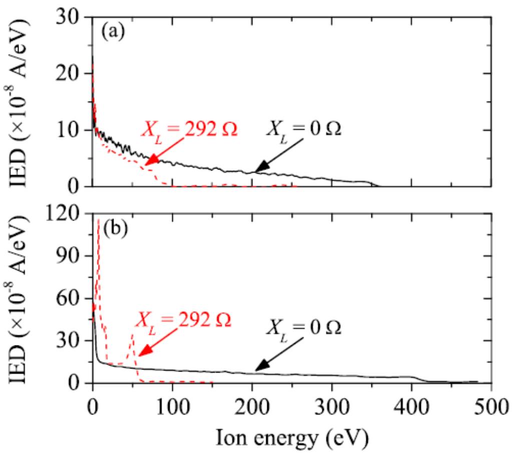

Fig. 1. Ion energy distribution (IED) in CCRF discharges [4]. IEDs are modified via the impedance controller connected with the wafer stage. The impedance at the wafer stage is controlled by the reactance of the controller, X_L. (a) and (b) correspond to RF power of 300 W and 1000 W, respectively.

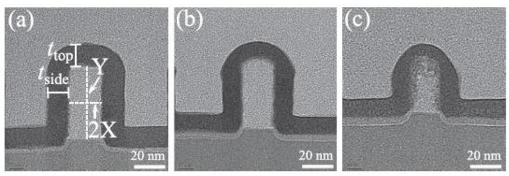

Fig. 2. TEM images of TiO_2 films deposited on a-C patterned substrates [5]. The mean ion energy, $\langle \varepsilon_i \rangle$, in CCRF discharges is (a) 23 eV, (b) 73 eV and (c) 133 eV, respectively.