Development of the virtual metrology for the nitride thickness in multi-layer plasma-enhanced chemical vapor deposition using plasma-information variables

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Insemiconductor-fabrication industry, virtual metrology (VM) is one of promisingtechnology to achieve advanced process control (APC) for plasma-assistedprocess because it can provide metrology data for every wafer. VM is defined asthe technology of prediction of metrology variables using process state(equipment and sensor) and wafer state variables. However,as the requiredprediction reliability of VM is getting higher, previouslydeveloped VM models face the degradation of prediction accuracy as the reactor-wallcondition drifts in long-term process. In line with this trend, a phenomenological-based virtual metrology (VM) based onplasma-information (named PI-VM) is developed for predicting the siliconnitride film-thickness in nitride/oxide multi-layer plasma-enhanced chemicalvapor deposition (PECVD). Particularly, the analysis of optical emissionspectroscopy based on the excitation kinetics in nitrogen plasma is used todevelop plasma-information (PI) variables. One variable, PI_{Wall}, isdetermined by analyzing the light transmittance of the nitrogen emissions atthe contaminated window, representing the drift of reactor-wall condition. Theother variable, PI_{Volume}, is determined by analyzing vibrationaldistribution of $N_2(C^3\Pi_u$, v=0+4) states, representing thedrift of electron-impact collisionsin plasma. These PI variables are applied as part ofinput variables of VM to improve the prediction accuracy. The partial leastsquares regression (PLSR) is adopted as the statistical method. Compared toconventional VM, PI-VM improves theprediction reliability at high values even for drifting process by combining plasmaspectroscopy, data mining techniques, and physics of low-temperature plasma. The evaluation of influence of each variable on PI-VM shows thatPI_{Wall} is the highest contributing variable and that PI_{Volume}further improves prediction reliability at the latter region of layers. Itmeans that the nitride film thickness is drifted or deviated from targetprocess result due to the drift of process environment, such as electron-impact collisions in plasma and filmbuildup on reactor-wall. Therefore, it is expected that PI-based monitoringtechnology contributes to the development of advanced process control (APC) andfault detection and classification (FDC) for plasma-assisted processes by providinghigh quality data to interpret the cause of process drift or deviation.

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