Data-driven Development of Plasma Process: Time-series Optimization of Etching Conditions Based on Reinforcement Learning

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As the structure of semiconductor devices has changed from 2D to miniaturized 3D, the number of process-condition parameters has increased for fabrication with nano-scale accuracy. For example, in etching process, an etching condition of an etcher, called "recipe", usually has more than 100 parameters because the number of etching steps increases to obtain target etching profiles. Therefore, the process development period increases because the condition with a lot of parameters is difficult to optimize. In order to avoid the rising device-cost caused by the prolonged development period, rapid optimization of multi-step recipes to obtain target profiles is required. In this study, we propose the method to optimize multi-step recipes by utilizing reinforcement learning (RL), which is one of the semi-supervised learning methods specialized for time-series analysis. To apply RL to etching process, "states" of a control object must be observed during etching. However, our control object, that is, an etching profile cannot be directly observed.

In this study, we adopted interference spectra (IS) reflected from an etching sample as a state for two following reasons. The first reason is that IS data can be observed during etching by installing a transparent window at the upper part of a plasma chamber and constructing the optical path for incident and reflected lights. The second is that etching profiles are expected to be effectively controlled by controlling IS data because this data have a strong correlation with etching profiles. Therefore, recipes can be determined by RL in-situ and in real-time on the basis of IS data. We experimentally demonstrated the optimization of 5-step recipes for etching an L/S pattern sample. The target profile was a deep and vertical trench. As a result, an optimized recipe for the target profile was obtained within 100 experimental trials.