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Testing a scallop free vertical silicon etching by using a fast- and automatically-controlled RF plasma source

Kengo Hanaoka, Kazunori Takahashi and Akira Ando
Department of Electrical Engineering, Tohoku University
e-mail (speaker): k_hanaoka@ecei.tohoku.ac.jp

Over the past several decades, low-cost manufacturing of semiconductor devices has been carried out with increasing the wafer diameter, yielding high-volume and low-mix production, in Mega Fab. On the other hand, a new type of manufacturing concept, Minimal Fab, has been proposed and vigorously developed in recent years. Minimal Fab System can yield high-mix and low-volume production of semiconductor devices, where a half-inch diameter wafer is treated in compact processing tools [1,2]. In order to make economical benefit in Minimal Fab, high-speed processes are required in various processes, e.g., Bosch type silicon etching for MEMS devices, where the formation of scallop on the etched side wall, which arises from the alternative processes of etching and passivation, is often desired to be minimized. It is expected that high speed switching of the alternative processes would be useful for inhibiting the scallop formation; precise temporal control of these processes is required when increasing the etching rate by using a high-density plasma.

Here, a compact helicon plasma source is employed to the etching tool. To temporally control the etching process, the RF power for the plasma production has to be pulsed and then the impedance tuning has to be accomplished in very short time. Therefore, a frequency-variable impedance tuning is utilized in the present experiment, where the traditional matching circuit including two variable capacitors can be replaced by two small fixed capacitors [3,4].

Figure 1 shows a compact helicon plasma reactor consisting of an insulator source tube wound by an RF antenna and a solenoid providing an axial magnetic field. A 50-mm-outer diameter alumina source tube is attached to a 114 mm cubic chamber evacuated by a turbomolecular pumping system. Sulfur hexafluoride (SF_6) gas and octafluorocyclobutane (C_4F_8) gas are introduced from the upstream side of the source via a mass flow controller. A DC current is supplied to the solenoid placed at z = -45 mm, where z = 0 is defined as the open source exit. A double-turn RF antenna is wound around the alumina tube at the axial position close to the solenoid center and powered from the RF amplifier for the plasma production. The device has a Si wafer stage and distance between the Si wafer and the RF antenna is about 60 mm. The RF power can be simultaneously supplied to both the RF antenna and the wafer stage, yielding a high-density plasma via inductively-coupled or helicon mode and a self-bias of the Si wafer for ion etching, respectively. This operation is performed by using a recently developed fast- and automatically-controlled frequency-tunable system [5] within a RF frequency range of 37-43 MHz, where the driving RF frequency and the output power are controlled by using a single board RIO controller (National Instruments) including a FPGA module and DA/AD convertors. This system can yield the high speed and stable impedance tuning within about a ten of msec and maintain a net power corresponding to the forward minus reflected powers at a constant level with good reproducibility [6]. The experiment of the isotropic etching in a steady-state SF_6 plasma shows a maximum etching rate above 10 µm/min for a Si substrate.

Figure 2 shows a SEM image of Al mask patterned Si substrate processed by Bosch process, where the gas flow rates are precisely controlled by using mass flow controllers. Figure 2 represents that Si substrate is etched vertically and no visible scallop structure can be seen. The detailed results will be shown in the presentation.

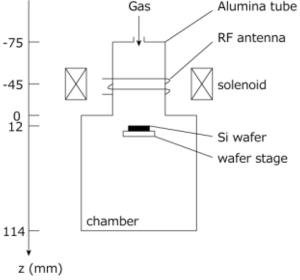

Fig. 1. Schematic diagram of the helicon reactor.

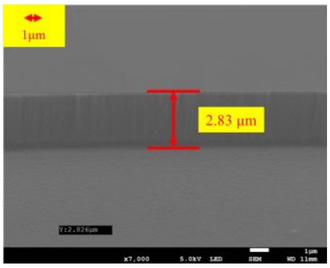

Fig. 2. SEM image of Al mask patterned Si substrate processed by Bosch process.

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