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Energy control of neutral oxygen particles passing through an aperture electrode

Takeo Ohno [a,b,*], Daiki Nakayama [c], Takeru Okada [c], Seiji Samukawa [a,c]

[a] WPI – Advanced Institute for Materials Research (WPI-AIMR), Tohoku University, 2-1-1 Katahira, Aoba-ku, Sendai, Miyagi 980-8577, Japan
[b] Japan Science and Technology Agency (JST), PRESTO, 4-1-8 Honcho, Kawaguchi, Saitama 332-0012, Japan
[c] Institute of Fluid Science (IFS), Tohoku University, 2-1-1 Katahira, Aoba-ku, Sendai, Miyagi 980-8577, Japan

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ABSTRACT

The kinetic energy of neutralized oxygen particles passing through an aperture electrode was measured by a quadrupole mass spectrometer. The peak energy position was controlled by changing the plasma source power, acceleration bias power, and gas pressure in the vacuum chamber.

Nanometer-thick metallic oxide films are widely used in various nanoelectronic devices, such as resistive random access memory (ReRAM) and complementary metal-oxide-semiconductor (MOS) transistors. To form these films, the sputtering technique and atomic layer deposition are commonly used. Recently, we proposed a metallic oxidation method using a neutral oxygen beam and succeeded in forming tantalum oxide (Ta_2O_5)-based ReRAM [1] and a germanium (Ge) MOS gate stack structure with an alumina (Al_2O_3) film [2].

One of the merits of the neutral beam generation method [3,4] is the controllability of the kinetic energy of oxygen particles in the lower energy range. In this study, the energy of neutral oxygen particles was experimentally estimated using a quadrupole mass spectrometer (QMS).

Fig. 1 shows the system for generation of the neutral oxygen beam. It consists of a plasma chamber and a sample process chamber, which are separated by a silicon (Si) aperture electrode with numerous holes and a high aspect ratio. The size of hole and plate are 1 mm in diameter and 10 mm in length, respectively. These holes were machined by drilling. In this system, almost all of the ions from the oxygen plasma are neutralized by charge exchange collision with the inner walls of the apertures [5]. Simultaneously, plasma particles passing through the electrode are collimated, and their flux is reduced owing to the small piping conductance. The aperture electrode also eliminates ultraviolet (UV) photons, electrons, and charged particles from the plasma, and prevents occurrence of a sheath region in the sample chamber. In this paper, the aperture electrode made of *p*-type bulk Si (resistivity: 1–50 Ω cm) was used, whereas a carbon aperture was applied when gases such as chlorine, argon and nitrogen were used [3–7]. This is to prevent the degradation of the aperture due to the reaction between oxygen gas and aperture material.

The beam energy measurements were performed with a QMS fitted with an energy analyzer [3,4,6], where the residual oxygen ions ($m/z = 32$) were detected. As a standard condition to generate the neutral oxygen beam, ICP source power of 500 W, bias power of 0 W, and oxygen pressure at the sample chamber of 0.1 Pa were used. Fig. 2 shows a typical QMS spectrum of the detected ions, which contains a sharp peak with a full width at half maximum (FWHM) of approximately 2 eV.

Fig. 3 shows the peak positions of the oxygen beam energy as a function of the source power for inductively coupled plasma (ICP, 13.56 MHz) generation. The beam energy increases with increasing ICP power. Fig. 4 shows the beam energy plotted as a function of the acceleration bias power. Here, a radio frequency (RF) bias with 600 kHz was applied to the Si aperture electrode. As a result, the beam energy monotonically increases with increasing bias power above 5 W. Therefore, the energy of the oxygen particles passing

* Corresponding author at: WPI – Advanced Institute for Materials Research (WPI-AIMR), Tohoku University, 2-1-1 Katahira, Aoba-ku, Sendai, Miyagi 980-8577, Japan.
E-mail addresses: t-ohno@tohoku.ac.jp (T. Ohno), samukawa@ifs.tohoku.ac.jp (S. Samukawa).

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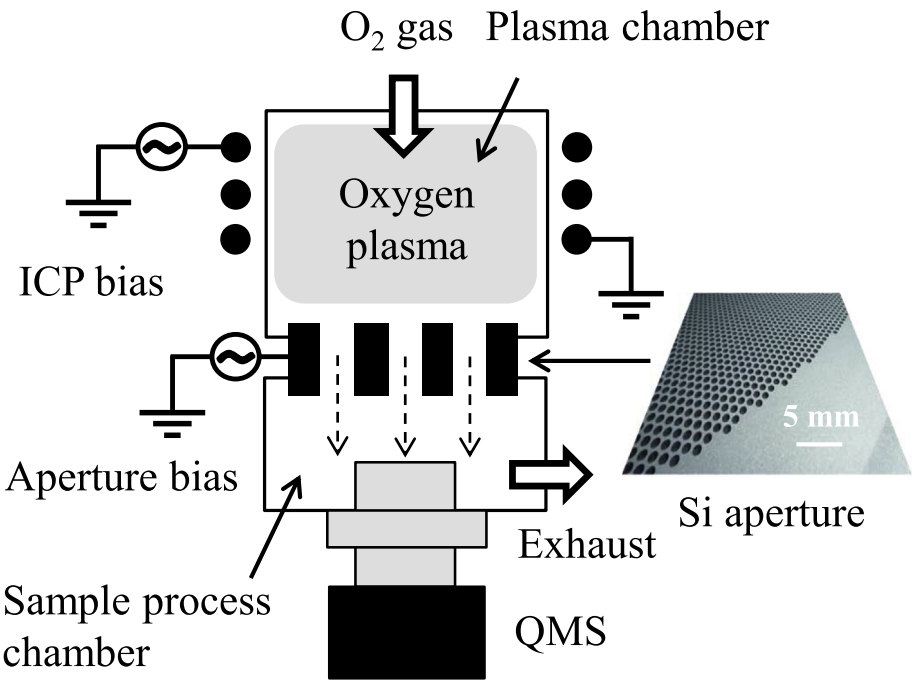

Fig. 1. Schematic diagram of the neutral beam generation system.

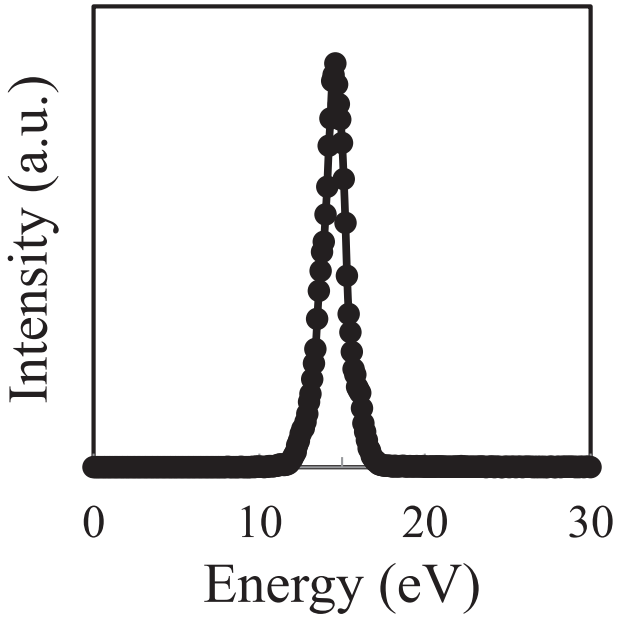

Fig. 2. Typical energy distribution of residual oxygen ions measured with a QMS. In this figure, ICP source power, bias power, and oxygen pressure were 500 W, 0 W and 0.1 Pa, respectively.

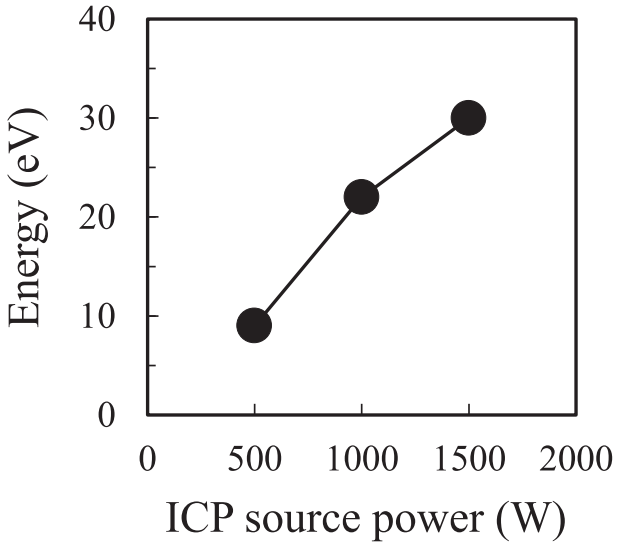

Fig. 3. Oxygen beam energy as a function of the ICP plasma source power.

through the aperture is controllable in the range 10–80 eV by changing the plasma source power and aperture bias power.

A beam energy of less than 10 eV can be obtained by adjusting the gas pressure in the sample process chamber (or the plasma chamber). Fig. 5 shows the peak energy positions for different oxygen pressure conditions. The beam energy decreases as the pressure is increased. A similar tendency has been reported using nitrogen and argon gas [6,8,9]. By applying this method, the energy of the oxygen particles can be precisely controlled in the range less than 10 eV, which can serve a low oxidation rate to form a very thin oxide film [10].

In summary, the energy of neutral oxygen particles passing through a Si aperture electrode has been measured with a QMS. The beam energy can be controlled by changing the ICP plasma source power, Si aperture bias power, and oxygen pressure in the vacuum chamber to generate oxygen particles with kinetic energies of less than 10 eV to around 80 eV. Because the beam energy affects the composition of the beam-treated thin film [2,6], energy-controlled oxygen particles will be useful for formation of thin metallic oxide films.

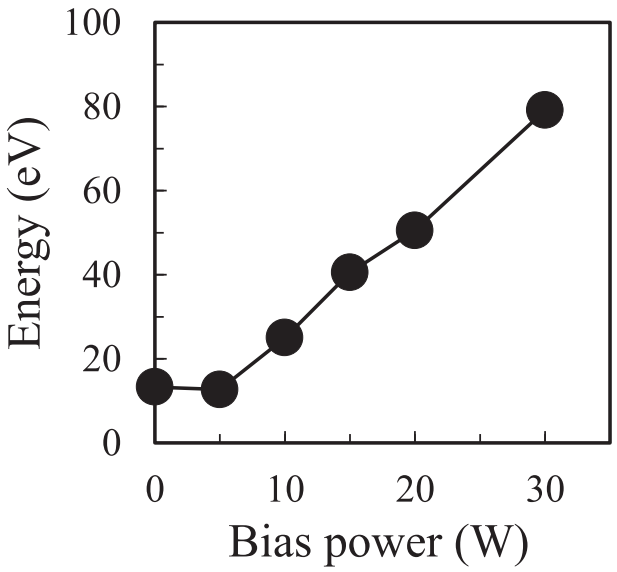

Fig. 4. Oxygen beam energy as a function of the acceleration bias power of the Si aperture.

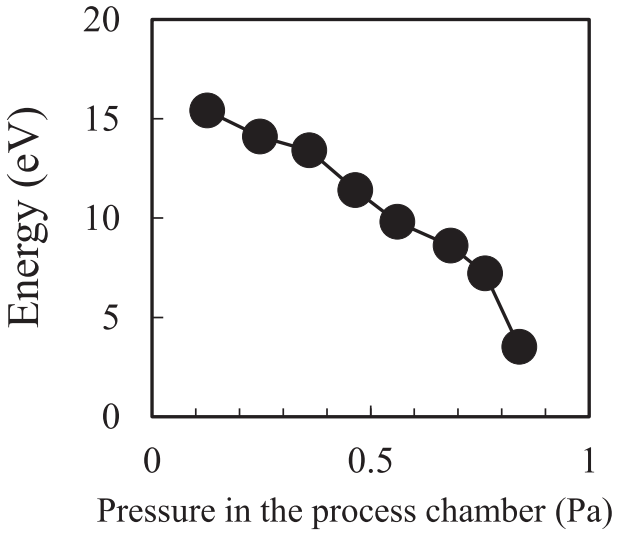

Fig. 5. Oxygen beam energy as a function of the oxygen pressure in the sample process chamber.

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