S-O4-2

Study of plasma-surface reactionsbya multi beam system

イオン・ラジカルビームによるプラズマ表面反応のシミュレーション実験

Kazuhiro Karahashi, Satoshi Hamaguchi
唐橋一浩，浜口智志

DCenter for Atomic and Molecular Technologies, Graduate School of Engineering,OsakaUniversity, 2-1 Yamadaoka, Suita, Osaka 565-0871, Japan
大阪大学大学院工学研究科原子分子イオン制御理工学センター，〒565-0871 大阪府吹田市山田丘2-1

A multi-beam system has been developed for the investigation ofinteractions of reactive ionicand radical species with material surfaces in plasma etching for microelectronicsmanufacturing processes. The systemcan independently irradiate the sample surface witha mass-selected single-species ion beam and reactive molecular beams, by which etching reactions in plasma environments can be simulated on the sample surface in ultrahigh vacuum (UHV)conditions. Angular and time-resolved measurements of scattered/desorbed species aremadewith a rotatable quadrupole mass spectrometer (QMS). In-situ measurements of surface chemical states aremade by X-ray photoelectron spectroscopy (XPS) and Fourier transform infrared spectroscopy (FTIR).

Dry etching with reactive plasmas has been widely used in the fabrication of materials.For the development of integrated semiconductor devices, a more precise control of the etching process is required for further progress.It is known that reactive ion species and reactive neutral species, which are produced in plasma, play important roles in etching reactions. However, the mechanisms for such etching reactions have not yet been quantitatively understood because the individual reactive species cannot be controlled independently in the conventional etching apparatus.For a better understanding of etching reactions, it is necessary to clarify the roles of individual reactive ionsand neutral species.A beam experimental method is a highly useful tool for the investigation of interactions of individual species with surfaces. Some features of beam experiments are summarized in Table 1.Pioneering work by Coburn *et al.* using beam experimental methods clearly showed that silicon etching reactions on fluorinated surfaces are enhanced by energetic inert ion bombardment [1].Such previous studies provided useful qualitative understanding of silicon etching that uses only halogen gas.In practical applications, however, various etching reactions with different materials used in the manufacturing of semiconductor devices must be quantitatively understood for amore precise control of the etching processes and also the development of process simulations. Therefore it is important to perform a systematic study onindividual surface chemical reactions associated with reactive species contained in processing plasmas.

		Plasma etching	Plasma beam	Multi beam Ion/radical	
				Mass analyzed ion beam	Molecular beam
Ion	Species	mixed	mixed	pure	
	Flux (cm-2 s-1)	> 10^{15}	10^{14}- 10^{15}	10^{13}- 10^{14}	
	Energy	Wide distributed	monochromatic	monochromatic	
Radical	Species	mixed	mixed		pure
	Flux (cm-2 s-1)	> 10^{17}	10^{15}- 10^{16}		10^{13}- 10^{14}
Etching Product	Measurements	difficult	possible	possible	possible

Table 1 beam experiments

We have developed a multi-beam (i.e., ion and radical beam)system for the investigation of the

interactions of reactive ions with various material surfaces (Fig.1) [2] [3] [4] [5]. A photograph of the system is give in Fig. 1.

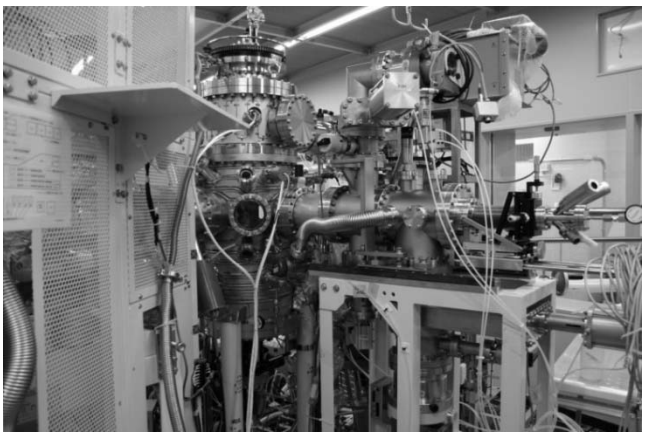

Fig.1. View of the multi-beam system

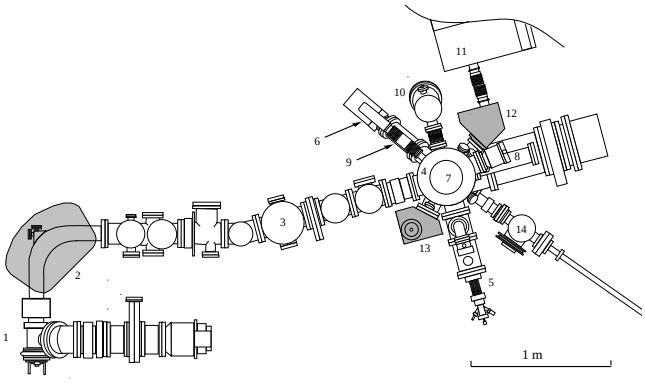

Fig. 2. A plane view of the multi-beam system.

A plane view of the beam injection system is given in Fig. 2. It consists of (1) an ion beam source, (2) a sector-type 90° mass selecting magnet, (3) an ion beam line with ion optics, (4) a reaction chamber, (5) a supersonic molecular beam source with a heatable nozzle, (6) an effusive molecular beam source with a radio-frequency (RF) plasma source, (7) a rotatable quadrupole mass spectrometer (QMS) for the measurement of scattered/desorbed species from the sample (8) a QMS with an energy analyzer for the beam characterization, (9) an X-ray source for X-ray photoelectron spectroscopy (XPS) [located above the molecular beam source (6)], (10) an electron energy analyzer for XPS, (11) Fourier transform infrared (FTIR) spectrometer, (12) IR optics, (13) a MCT detector for IR, and (12) a load lock chamber. (The number in the parentheses corresponds to the number of each label in Fig. 1.)

A sample (substrate), into which all the beams are to be injected, is placed in the UHV reaction chamber, where no atomic/molecular species other than those provided by the injected beams is designed to react with the sample surface. The mass selecting magnet selects only ionic species of a specified mass from the initial beam, which leaves only the ion beam of a single species in the rest of the beam line.

Figure 2 also schematically depicts how the ion and neutral beams can be injected into a substrate (sample) simultaneously in the reaction chamber. Charge neural beams of atoms, molecules, and/or radical species are provided by two molecular beams. An incident ion energy is measured with the QMS coupled with an energy analyzer, and angular and time-resolved measurements of desorbing molecules are performed with a rotatable QMS.In-situ measurements of the chemical states of molecules in the surface layer of the substrate are performed by XPS and FTIR.

In the presentation, details of some experimental results that have been obtained in the multi-beam will be also presented.

References

[1] J. W. Coburn, H. F. Winters, and T. J. Chuang: J. Appl. Phys **48**(1997) 3532.

[2]K. Karahashi*et al.*: J. Vac. Sci. Technol. A **22**(2004) 1166.

[3] K. Ishikawa and K. Karahashi*et al.*: J. Vac. Sci. Technol. A **21**(2003) L1..

[4]K. Yanai and K. Karahashi *et al.*: J. Appl. Phys **97**(2005) 53302

[5]T.Ito and K. Karahashi *et al.*: J. Appl. Phys **97**(2005) 53302