AXIC APPLICATION REPORT

GENERAL OVERVIEW ON DRY PROCESSING PRINCIPLES & PROCESS CLASSIFICATION 7

*by **Jozef Brcka**, AXIC, Santa Clara, California*

DRY ETCH PROCESSES can be classified according to several properties. For instance, etching mechanism, selectivity behavior, anisotropy, geometrical electrode configuration, frequency range, presence of magnetic field or other sources of energy, etc.. The most fundamental classification is related to character and mechanism of etching processes and to particles which are participating in reactions at the ***surface/plasma interface*** (Figure 1). This classification is in correlation with typical intervals of the basic technological parameters such are pressure and energy of active particles (Fig. 1). It gives direct answer to the question: ***Why plasma is used for material processing?***

Low temperature plasma is a unique FOURTH STATE OF AGGREGATION OF MATTER in which high energy electrons in a matrix of cold ions and other particles realize effective transfer of dc (rf) electric field energy by means of collisions to heavy particles, thus the last ones are becoming chemically active and can interact with a surface in a chemical or physical way.

TABLE 1
Classification of etching processes involving the plasma.

PLASMA PROCESSING (ETCHING)			
Physical interaction (ion assisted processes)	***Plasmochemical interaction (reactive radical interaction)***	***Physical-chemical interaction (synergetic interaction of ions and radicals)***	***Photon assisted interaction in plasma***
*The ions of inert gas are accelerated towards the substrates by the potential difference between the plasma body (or ion source) and electrodes. They are bombarding the surface and delivering the impulse to surface atoms - **the ion sputtering** process occurs.*	*The process uses chemically reactive gases and their mixtures. In plasma a variety of active particles (radicals, reactive ions) are produced.* *Surface atoms are chemically reacting with radicals on the surface, **producing volatile products.***	*The process uses physical and chemical interaction of active particles with the surface:* *The surface atoms are bonded more weakly due to chemisorbtion of radicals on the surface ⇒ they are more easily sputtered off. Probability of chemical reaction is higher on physically sputtered surfaces than on non-exposed surfaces;* *Ion bombardment provides energy essential for chemical (or ion-chemical) reaction*).*	*The chemical reactions on a surface are initiated by a photon beam in electrically neutral gas at low pressure or within a discharge.* *Etching is potentially anisotropic and selective.*
Physical etching is highly directional and a low selective process.	*Etching is isotropic and highly selective.*	**) For example, dissociation of adsorbed molecules into radicals, which can directly without migration react with surface.*	

TABLE 2
Characteristic values of plasma parameters.

Parameter	RIE Reactive Ion Etching	PE Plasmochemical Etching
Pressure	0.1-20 Pa (1-150 mtorr)	20-1000 Pa (150 mtorr-several torr)
Rf power	up to 1 kW	
Flow rate, cm^3/min (SCCM)	<50	10 - 500
Frequency	50 kHz - 27 MHz	(typically 13.56 MHz) up to microwave range
Particles and their energy, eV:		
Ions	0.1 - 0.5 keV	1 - 100 eV
Atoms and radicals	0.05 - 0.1 eV	
Electrons	several electronvolts	
Neutral atoms and molecules of working gas	0.05 - 0.1 eV	
Density of neutral particles, cm^{-3}	10^{13} - 10^{15}	10^{15} - 10^{18}
Density of charged particles, cm^{-3}	10^{9} - 10^{12}	
	• low density plasma sources	• high density plasma sources

REFERENCES

Reactive processes, principles and technical aspects are well described in several books, for example in: Abe, H., Nagatomo, M. and Yoneda, M.: Dry process technology (ed. Nishizawa, J.: Semiconductor Technologies), OHM - North Holland (1982) 100. Auciello, O. and Flamm, D.L.: Plasma diagnostics: Discharge parameters and chemistry, vol. I, Surface analysis and interactions, vol. II, Academic Press, Inc. Boston - Toronto(1989). Boenig, H.V.: Fundamentals of plasma chemistry and technology, Technomic Lancaster (1988). Brčka, J.: Plazmatické techniky, STU Bratislava (1996). Melliar-Smith, C.M. and Mogab, C.J.: Plasma assisted etching techniques for pattern delineation (in: Thin film processes, eds. Vossen, J.L. and Kern, W.) Academic Press, New York (1978). Rossnagel, S.M., Cuomo, J.J. and Westwood, W.D.: Handbook of Plasma Processing Technology. Noyes Publications, Park Ridge, NJ (1990).

Axic, Inc.
493 Gianni Street
Santa Clara, CA 95054-2414
Tel. (408) 980-0240 Fax (408) 980-0524
E-mail: postmaster@axic.com

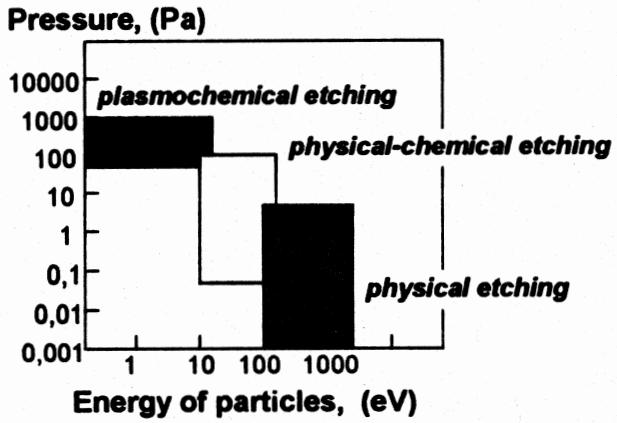

FIG. 1
Typical intervals of technological parameters for various etching processes.

Plasma is a partially ionized gas with equal numbers of positively and negatively charged particles. The negative charges are electrons with density in range $n_e = 10^8 - 10^{12} cm^{-3}$ and the positive charges are ions with density $n_i = 10^8 - 10^{12} cm^{-3}$. The typical range of neutral atom and molecule density is $n = 3.5x10^{16} cm^{-3}$ at 1 Torr. The degree of ionization is in the interval of $10^{-4} - 10^{-6}$ (or 100 - 1 ppm). The ions within a plasma have a low energy of about $2kT_i/3 = 0.04eV$. They are heavy and accelerate slowly. Whatever energy they gain between collisions is dissipated effectively in elastic and inelastic collisions with neutrals of compatible mass and T_i remains close to room temperature, e.g. the ions are ***"cold"***.The electrons within plasma have high energy, that is $2kT_e/3 = 2 \div 8eV$. They are light and accelerate fast. They lose little energy in elastic collisions with heavy neutrals and continue to gain energy between collisions up to T_e = 10^4 to 10^5 K. The electrons are ***"hot"***. Hot electrons in cold plasma are responsible for the plasma environment which enables processes normally requiring very high temperature.

Typical values of technological and plasma parameters in plasmochemical and reactive ion etching processes are given in Table 2.

TABLE 2
Characteristic values of plasma parameters.

Parameter	RIE Reactive Ion Etching	PE Plasmochemical Etching
Pressure	0.1-20 Pa (1-150 mtorr)	20-1000 Pa (150 mtorr-several torr)
Rf power	up to 1 kW	
Flow rate, cm^3/min (SCCM)	<50	10 - 500
Frequency	50 kHz - 27 MHz (typically 13.56 MHz) up to microwave range	
Particles and their energy, eV:		
Ions	0.1 - 0.5 keV	1 - 100 eV
Atoms and radicals	0.05 - 0.1 eV	
Electrons	several electronvolts	
Neutral atoms and molecules of working gas	0.05 - 0.1 eV	
Density of neutral particles, cm^{-3}	10^{13} - 10^{15}	10^{15} - 10^{18}
Density of charged particles, cm^{-3}	10^9 - 10^{12} • low density plasma sources	• high density plasma sources

493 Gianni Street, Santa Clara, CA 95054-2414
Tel. (408) 980-0240 Fax (408) 980-0524
E-mail: postmaster@axic.com

REFERENCES

Reactive plasma processes are well described in several books: Boenig, H.V.: Fundamentals of plasma chem. and tech., Technomic Lancaster (1988); Rossnagel et al.: Handbook of Plasma Processing Technology. Noyes Publications, Park Ridge, NJ (1990); Grill, A., Cold Plasma in Materials Fabrication, p. 153, IEEE, New York (1994), etc.