

(b) In new driving mode  $\omega = \omega_0/2$ ,  $\varphi = -\pi/4$ , at  $SM \gg B$ ,  $\omega_0 \approx \sqrt{S/M}$

$$\bar{a}(t) = (C_0/2B\omega_0 X_p)(V_d^2/4)(1 - e^{-\alpha t}) \cos \omega_0 t \\ = (\bar{F}_h/2\omega_0 B)(1 - e^{-\alpha t}) \cos \omega_0 t. \quad (8)$$

The results show that under a step driving the amplitude of vibrating diaphragm varies with  $(1 - e^{-\alpha t})$  law. Because  $\alpha$  depends on gas pressure  $P_0$ , one can measure  $\alpha$  to determine  $P_0$ .

### 3. The output signal and measurement

The vibration of diaphragm causes the modulation of capacity between the insulated detection electrode and the grounded diaphragm. The ac capacitance is  $C = C_0[1 - (a_m/2X_p) \cos \omega_0 t]$ . When a dc bias voltage  $V_{s2}$  is applied to the detection electrode, the modulated capacitance produces an ac output signal on the detection electrode, i.e.

$$U_0 = V_{s2}(a_m/2X_p)\{\omega_0 C_0 R / \sqrt{1 + [\omega_0 R(C_0 + C_s)]^2}\} \\ \times \cos[\omega_0 t - (\pi/2 + \psi)] \quad (9)$$

where  $C_s$  = parasitic capacitance of measuring circuit and  $R$  = input resistance of measuring circuit. We have divided the measurement methods into two kinds:

(a) Voltage measurement method. Here  $\omega_0 R(C_0 + C_s) > 4$ , therefore

$$|U_0| = V_{s2}(a_m/2X_p)[C_0/(C_0 + C_s)]$$

and

$$|\psi| = \arctg[\omega_0(C_0 + C_s)R] > 76^\circ. \quad (10)$$

If  $U_0$  is fixed, the gauge is operating with a constant vibrating amplitude of diaphragm. The main problem is that the output signal at the detection plate varies with the change of parasitic capacitance.

(b) Current measurement method. Here  $\omega_0 R(C_0 + C_s) < 0.25$ , therefore

$$|i_0| = |U_0|/R = V_{s2}(a_m/2X_p)\omega_0 C_0$$

$$|\psi| < 14^\circ. \quad (11)$$

The main advantage of this method is that the output signal is independent on  $C_s$ . The gauge acts as a constant current source.

In Table 1 the experimental values of the relative output signals are given for various  $C_s$ . The experiment is consistent with Equations (10) and (11).

These results above are summarized in the form of output signals for the two methods and two driving modes as follows:

	Normal Mode	New Mode
Voltage method: $ U_0 $	$\frac{V_d V_{s1} V_{s2} C_0^2}{2B_0 X_p (C_0 + C_s)}$	$\frac{V_d^2 V_{s2} C_0^2}{8B_0 X_p (C_0 + C_s)}$
Current method: $ i_0 $	$V_d V_{s1} V_{s2} C_0^2 / 2BX_p$	$V_d^2 V_{s2} C_0^2 / 8BX_p$

Table 1. Measuring values of  $|U_0|/|U_0|_{C_s=0}$  vs  $C_s$

$C_s$ (pf)	0	51	102	153
Voltage method	1.0	0.61	0.46	0.34
Current method	1.0	1.0	0.99	0.92

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### Scrubbing of Cl-containing plasma waste gases

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Plasma processing has emerged as an important technology for the deposition and etching in the manufacture of microelectronic devices. With the introduction of dry etching processes, there was some hope to avoid the severe waste disposal problems inherent to wet-etch technologies. The materials of microelectronics devices as Si, poly-Si, *n*-Si, *p*-Si, SiO<sub>2</sub>, PSG, Al and Al-alloys, refractory metals and metal silicides and GaAs are etchable by Cl- and/or F-containing gases and mixtures of them with Cl<sub>2</sub> and N<sub>2</sub> as well as with "diluting" inert gases. In many cases, the enhanced demands of  $\mu$ m and sub- $\mu$ m patterning require preferentially Cl-containing etch gases and etch gas mixtures because by different mechanisms anisotropic etching processes and 1:1 mask:structure dimensions are possible.

The used halocarbons, but also carbon-free compounds as BCl<sub>3</sub>, SiCl<sub>4</sub>, SF<sub>6</sub> and Cl<sub>2</sub> are characterized by a very complex plasma chemistry which in the tendency is comparable to high temperature decomposition processes. As a result of plasma decomposition, a broad spectrum of products is obtained due to decomposition of the feed gas, and reactions with the etched materials and the resist materials. When, as usual, an organic resist material is used, many carbon- and hydrogen-containing reaction products are produced even in carbon-free feed gases.

The following two schemes give a survey of the main products formed by plasma etching processes containing C/F and C/Cl compounds with increasing or decreasing ratio of these atoms realized by different starting mixtures, by addition of O- or H-containing admixed compounds or different consumption processes by etching of electrode materials, respectively.

The highly toxic reaction and decomposition products underlined are problematical on three fields. Firstly, the wall contamination of the vacuum equipment, secondly the exhaust gas contamination and last but not least – the chemical and tribochemical interaction within the pumping system.

The problem is not so much the content of one of the hazardous products at the moment of measuring<sup>1</sup> as more the accumulation of these products especially on the walls within as well as outside the vacuum system, which is enhanced by the contamination of these walls by reaction products of a high specific surface as SiO<sub>2</sub>, Al<sub>2</sub>O<sub>3</sub>, B<sub>2</sub>O<sub>3</sub> and metal oxides.

In the case of scheme 1, the gas-phase fluorocarbons are detected by gas chromatography and compared with the known hazardous decomposition products of PTFE-pyrolysis. The most dangerous substances are C<sub>4</sub>F<sub>5</sub> and C<sub>3</sub>F<sub>6</sub> while the saturated F-carbons have much higher maximum permissible concentrations ("MAK"-values). The formation of these products is favoured by low F/C ratios or H containing reaction gases used especially for realization of good SiO<sub>2</sub>/Si etch selectivities. Scrubbing of these substances which are stable from a chemical point of view by reactive solutions (KOH/alcohol) is imperfect. A further way which is comparable uses the pyrolytical decomposition on SiO<sub>2</sub> surfaces<sup>2</sup>.

## Scheme 1

	decreasing ← + F, O	C/F	increasing → + C, H,	
	C-consumption	1 : 4	F-consumption	
reaction products				
CF <sub>4</sub> , C <sub>2</sub> F <sub>6</sub>		CF <sub>4</sub>	C <sub>2</sub> F <sub>4</sub>	
C <sub>2</sub> F <sub>4</sub>		C <sub>2</sub> F <sub>6</sub>	C <sub>x</sub> F <sub>y</sub>	
COF <sub>2</sub>		C <sub>2</sub> F <sub>4</sub>	C <sub>2</sub> H <sub>2</sub> F <sub>2</sub>	
CO <sub>2</sub>		SiF <sub>4</sub>	C <sub>3</sub> F <sub>6</sub>	
SiOF <sub>2</sub>		F <sub>2</sub>	C <sub>4</sub> F <sub>6</sub>	
SiF <sub>4</sub>			C <sub>4</sub> F <sub>6</sub>	
deposition products:				
small content of		CF <sub>y</sub> -glow polymers		
CF <sub>x</sub> -glow polymers		carbon rich deposits		
refractory metal fluorides				

## Scheme 2

	decreasing ← + F, O	C/F	increasing → + C, H,	
	C-consumption	1 : 4	F-consumption	
reaction products				
Cl <sub>2</sub>		CCl <sub>4</sub>	C <sub>2</sub> Cl <sub>6</sub>	
COCl <sub>2</sub>		C <sub>2</sub> Cl <sub>6</sub>	C <sub>x</sub> H <sub>y</sub> Cl <sub>2</sub>	
CO		C <sub>2</sub> Cl <sub>4</sub>	C <sub>3</sub> /C <sub>4</sub> -fractions	
CCl <sub>4</sub>		Cl <sub>3</sub> Cl <sub>6</sub>	per-chloro-aromates	
C <sub>2</sub> Cl <sub>6</sub>		Cl <sub>2</sub>	(3) Dioxin	
			per-chloro-furanes	
deposition products:				
CCl <sub>x</sub> -glow polymers		glow polymers	CCl <sub>x</sub> -glow	
		polymers + reaction products		
refractory metal chlorides				
refractory metal-oxo-chlorides				

The further discussion will stress the scrubbing of the Cl-containing waste gases. The Cl-containing etching gases themselves are toxic, carcinogenic in different manner and sometimes (BCl<sub>3</sub>, SiCl<sub>4</sub>) of a very high reactivity. They form polymeric products which, most probably, are responsible, for the good anisotropy of the etching process. However, they are otherwise the source of a wide-spread contamination of the vacuum system, whereby Cl-carbons are most effective. Calculations of the products distribution of chlorocarbons in dependence of the temperature show that one of the most stable products at temperatures above 1000 K is the C<sub>6</sub>Cl<sub>6</sub>, which may be one of the starting products for the formation of further perchloro-aromatic compounds. Under the reaction conditions of the nonisothermal low pressure plasma used for the etching processes, one of the most important differences against the high temperature reaction conditions is the dominance of wall recombination reactions which enhance the formation of aliphatic Cl-carbons as C<sub>2</sub>Cl<sub>6</sub> especially, while the aromatic products mentioned above are of rather low concentration.

With the Lewis acids as BCl<sub>3</sub> and AlCl<sub>3</sub>, reaction partici-

pants must be considered which enhance the complexity of the reaction manifold considerably, BCl<sub>3</sub> seems to react under some conditions also with the pumping oil Fomblin<sup>R</sup>, a polyperfluoroether, which is usually regarded to be inert.

The described facts, which can not be solved by flame pyrolysis and liquid phase scrubbing alone<sup>3</sup> make it desirable to scrub the Cl-containing products within the vacuum equipment already. As a first possible way into this direction, a Fe containing high temperature reactor was proposed<sup>4</sup>. At temperatures of 500°C to 800°C, Cl<sub>2</sub>, part of the Cl-carbons and, AlCl<sub>3</sub>/Al<sub>2</sub>Cl<sub>6</sub> will be retained by formation of surface rich FeCl<sub>3</sub>/FeCl<sub>2</sub> which also captures most of the AlCl<sub>3</sub> and some Cl-carbons. The life-time of pumping systems with mineral oils is drastically enhanced. The regeneration of the reactor is possible by a water treatment with following annealing and exchange of the Fe-insertion. The reactor may be regarded as a specific system reducing the waste gas problems without delivering a general solution of all problems.

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## Performance studies of partial pressure analysers

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Unlike a hot-cathode ion gauge, a quadrupole partial pressure analyser (PPA) may exhibit a significant deviation from linearity in its output signal vs partial pressure relation over a wide pressure range. Further, the influence of instrument parameters on this relation and on absolute sensitivity can differ widely among PPAs of similar design. Such characteristic behavior has been investigated for five different commercial quadrupole PPAs in use in the authors' laboratory. Employing only Faraday cup ion detection, the following characteristics were evaluated: variation of sensitivity (Amp/Pascal) with instrument parameters (electron emission, electron energy, ion energy, and resolution); linearity, i.e. change in sensitivity with pressure; variation of linearity with instrument parameters; dependence of sensitivity on gas species; change in sensitivity with time over the short term (days) and over the long term (months), with intervening exposure to various gases; and the effect of the presence of one gas at different pressures on the sensitivity to another gas.

In the three instruments with adjustable electron energy, maximum argon sensitivity was obtained at electron energy settings 40–60 eV below that for maximum argon ionization cross section (90 eV). In argon at 10<sup>-4</sup> Pa, the ion current vs electron emission current (*I<sub>e</sub>*) relation in one of the instruments was not even monotonic; in the other two instruments with adjustable *I<sub>e</sub>*, the ion current saturated, so that no further gain was realized by increasing *I<sub>e</sub>* above about 0.3 mA in one case,