Corrosão (*etching*) seca

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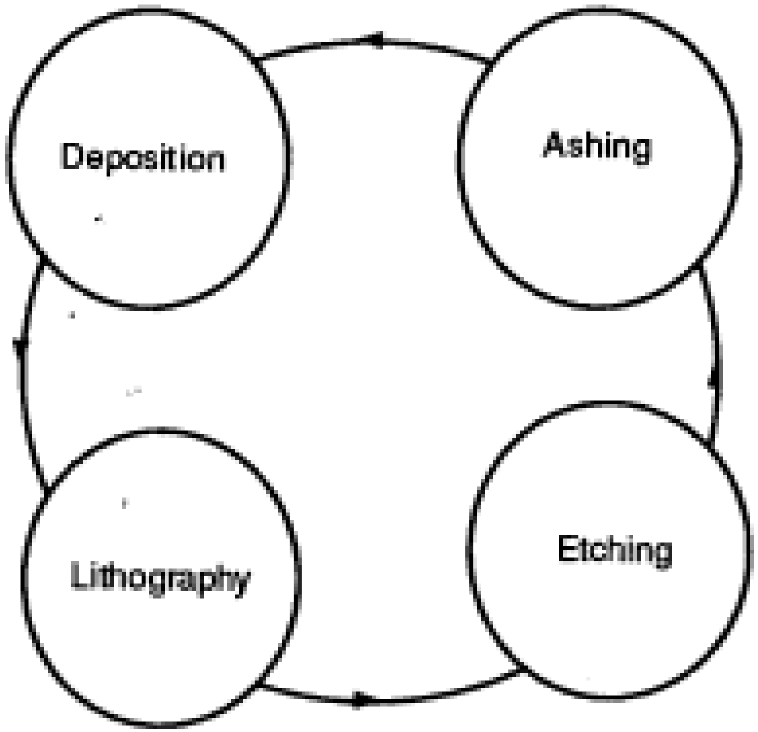
Processos em micro-fabricação: ciclo típico

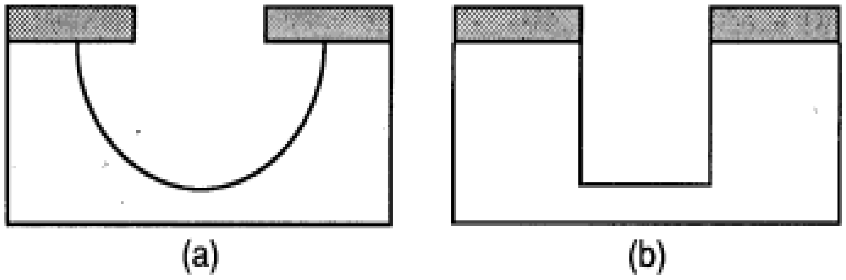
- **deposição** de filmes finos (semicondutor, metal, dielétrico, etc.)
- **litografia** (fotorresiste / gravação com luz UV ou feixes de elétrons)
- ***etching*** (**corrosão**) - tratamento (modificação) e remoção do material não coberto por fotorresiste
- **remoção** de fotorresiste



Schematic process cycle.

Corrosão: principais requerimentos

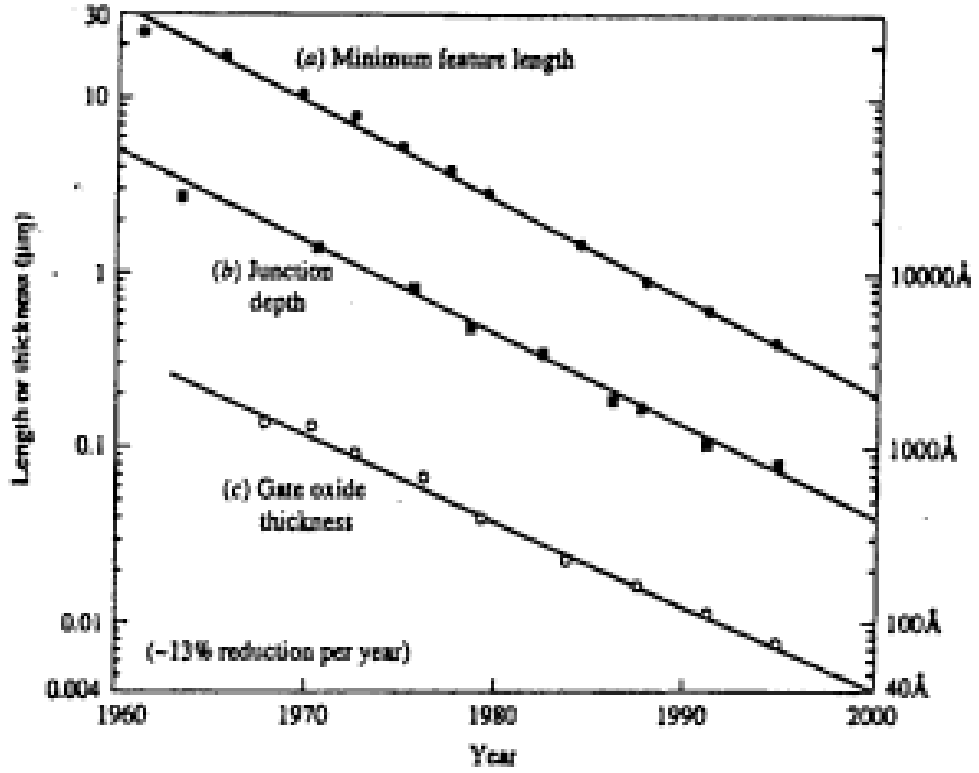
- **Anisotropia**
- **taxa** de ataque
- **seletividade** (Si/SiO_2/fotorresiste)
- **defeitos** (elétricos, estruturais, contaminação)
- **uniformidade** (lâminas de Si: 200 mm $\rightarrow$ 300 mm)



Schematic illustration of (a) isotropic and (b) vertical etching.

Corrosão:

- Tendência principal da microeletrônica: diminuição de tamanho característico de estruturas para escala **sub-micron - nano**

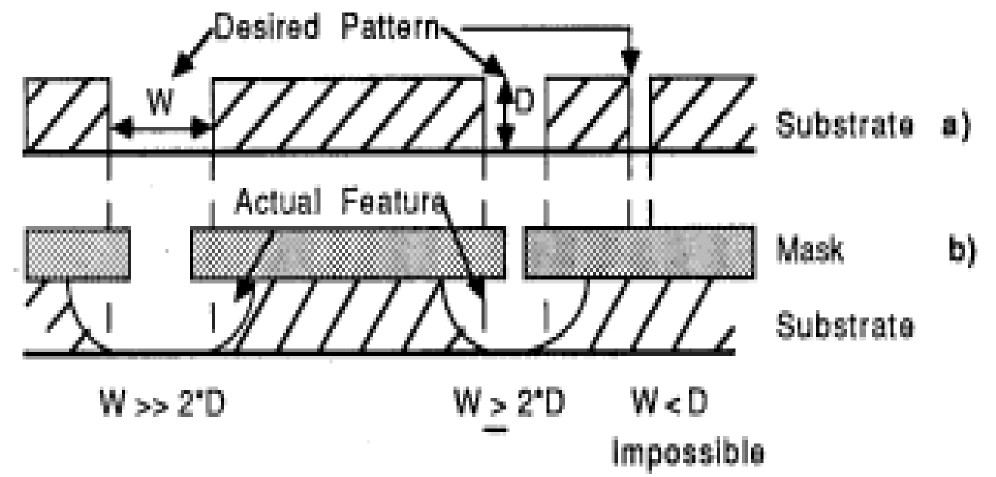


Exponential decrease in transistor size and film thickness.

Corrosão úmida :Característica geral

Vantagens:

- simplicidade
- rápida (taxa de ataque $\geq 1\mu m$ /min)
- seletividade - alta



Problemas:

- isotrópica (geralmente)
- uniformidade
- impurezas
- reagentes: caros, tóxicos, reciclagem- difícil

Corrosão seca: uma solução do problema de anisotropia em escala sub-micron

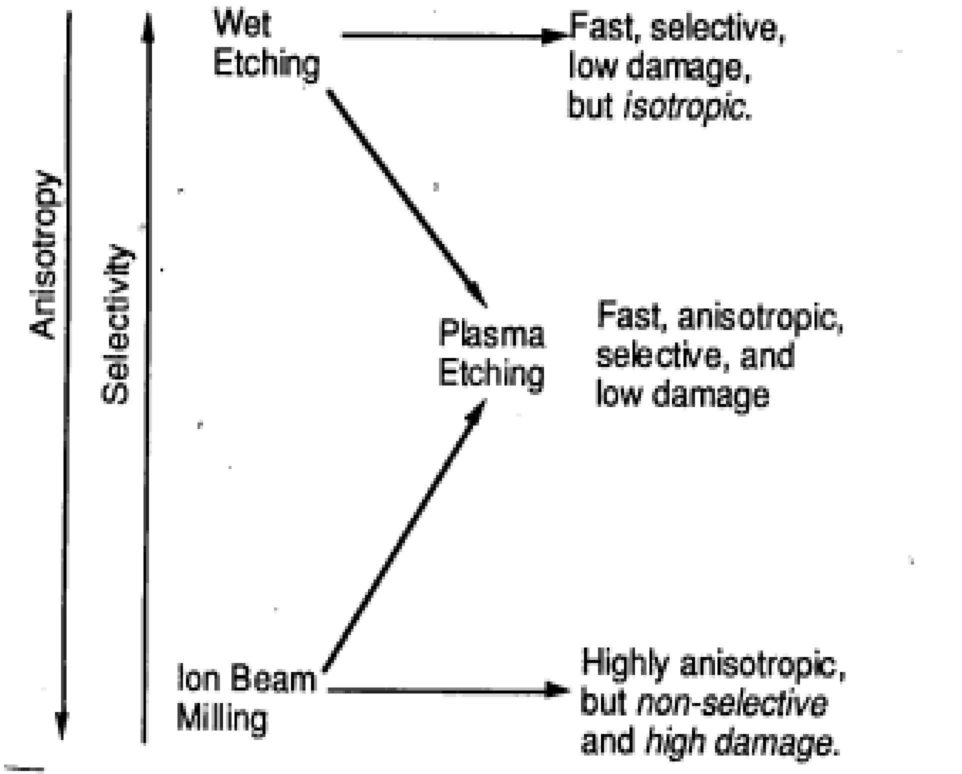
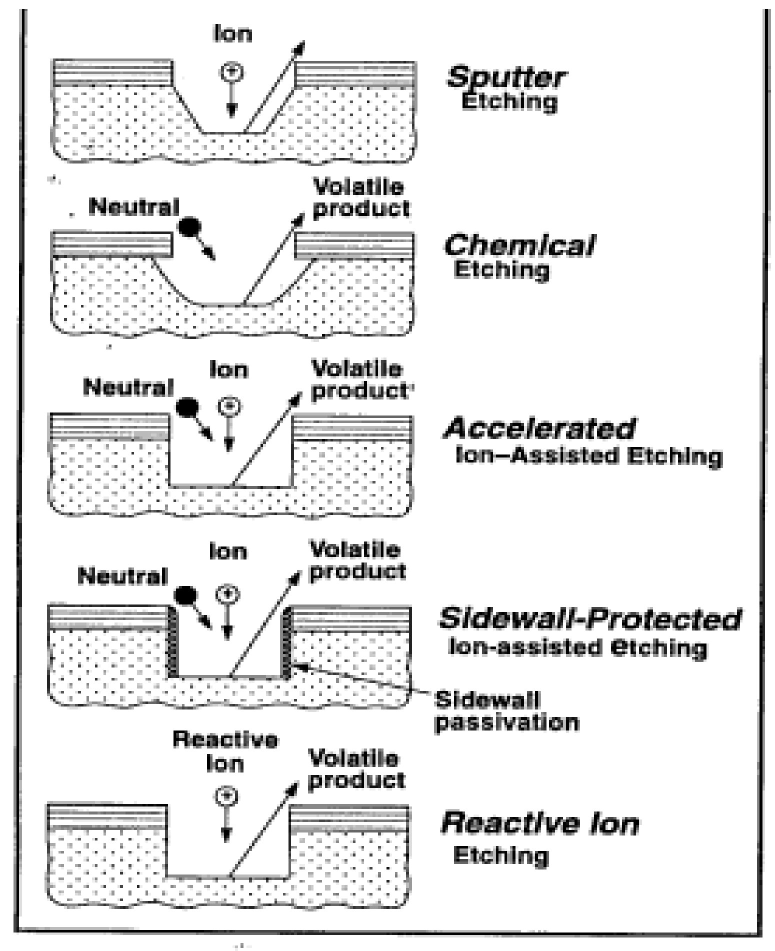


Illustration of plasma etching integrating chemical and physical etching.



The Five Classes of Etching Mechanism

Tendências básicas

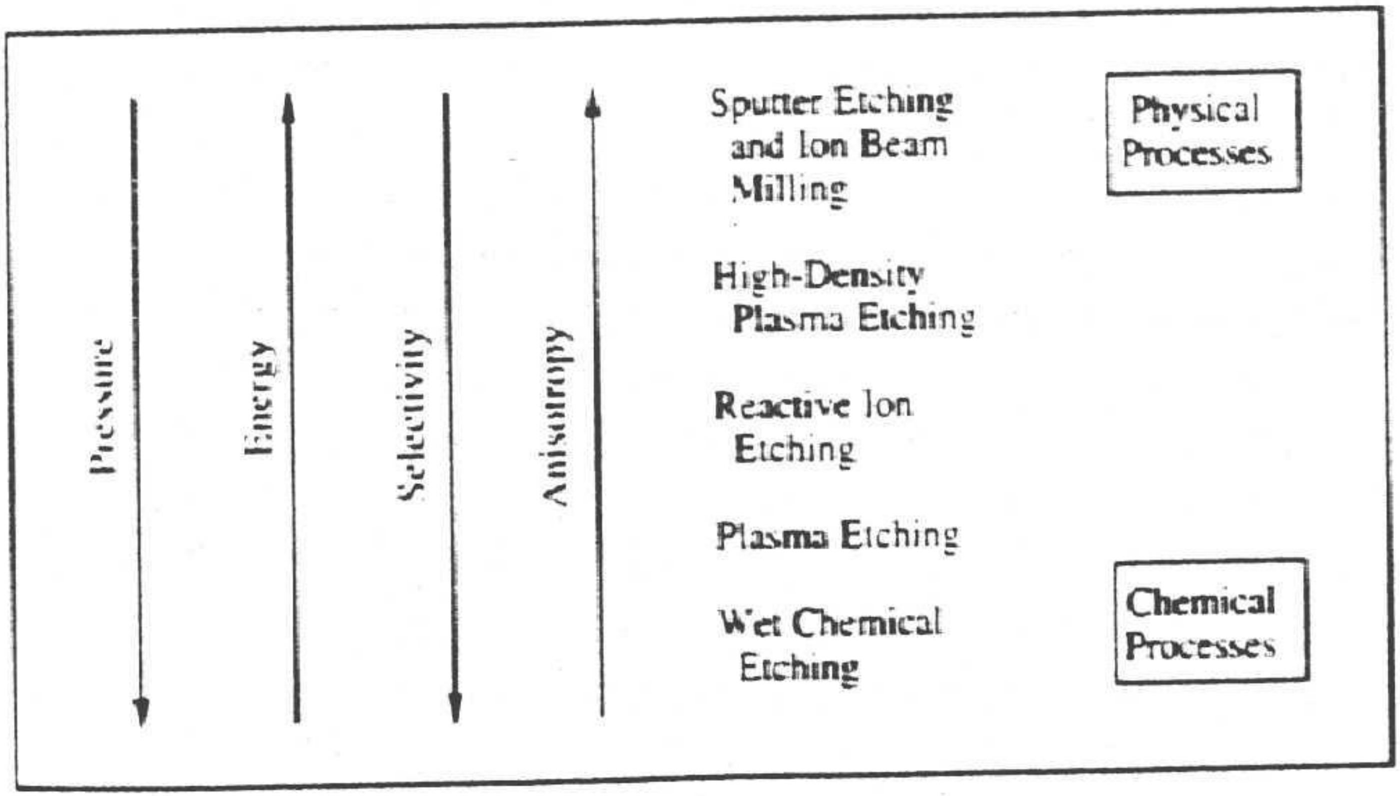
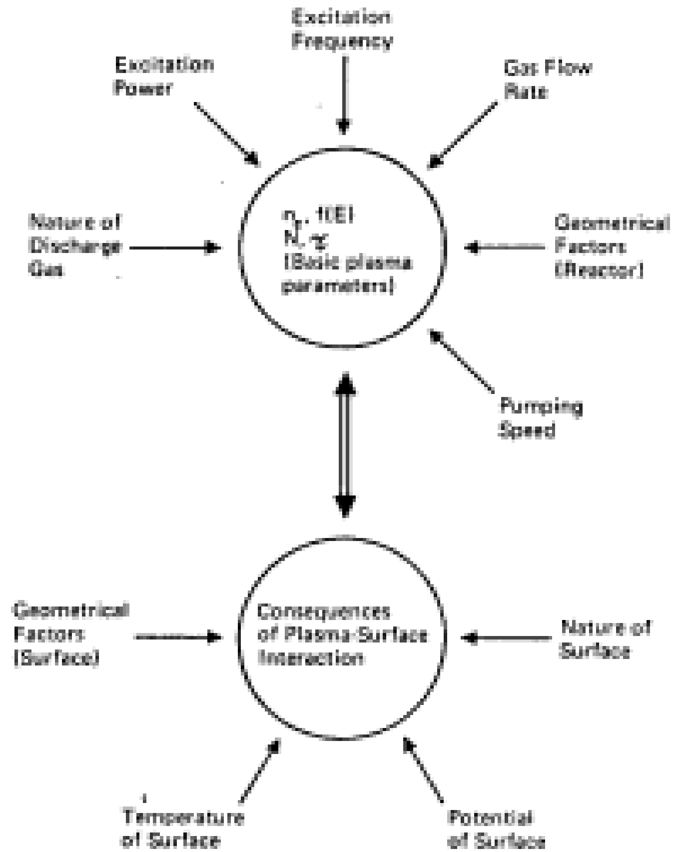


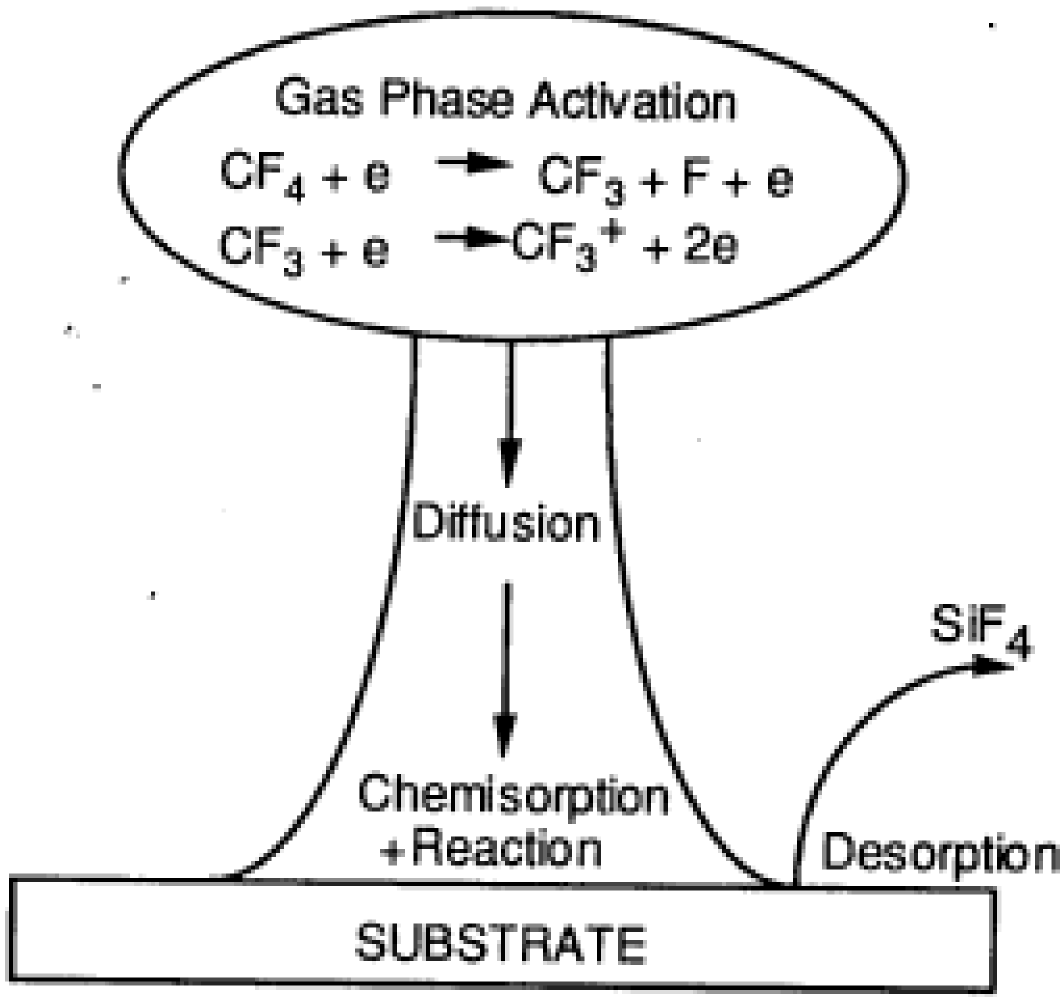
Figure 10–19 Summary of trends of different etch systems.

Plasma de descarga elétrica: um sistema complexo com parâmetros interdependentes



Representation of the parameter problem in plasma etching systems (n_e is the electron density, f (E) is the electron energy distribution function, N is the gas density, and τ is the residence time

Processos em plasmas reativos :

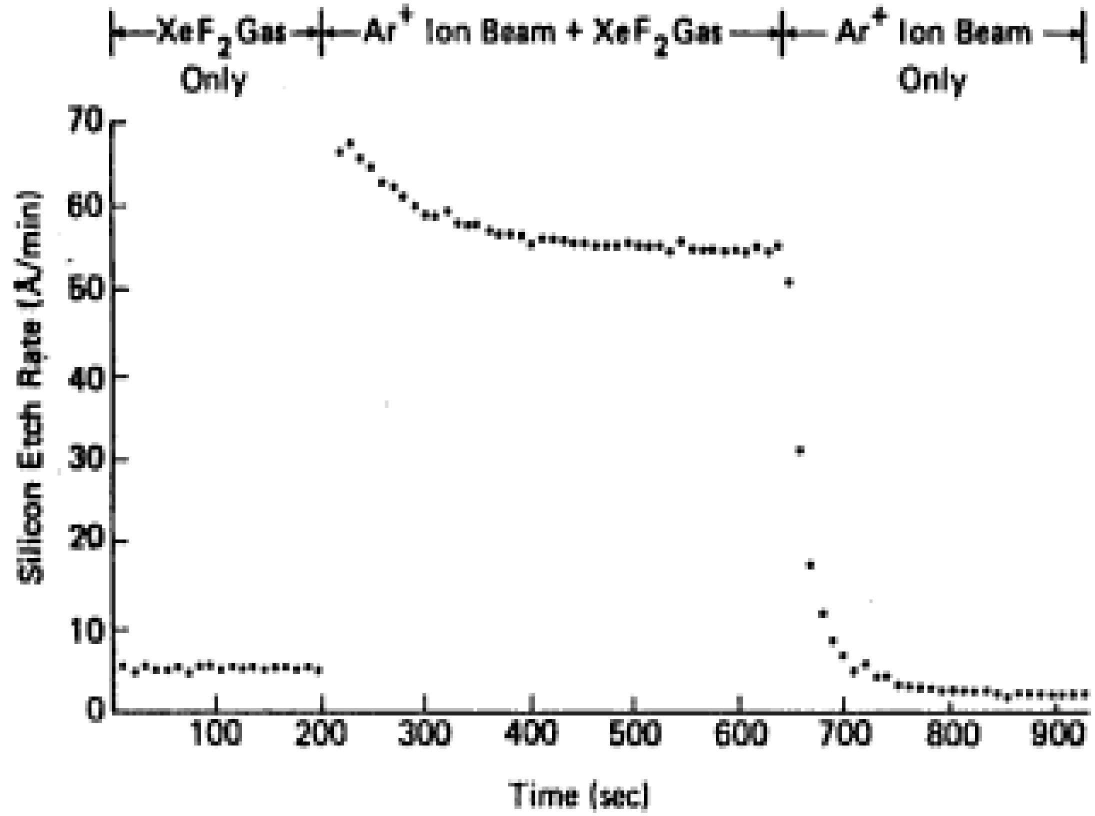


Schematic illustration of Si etching in CF_4 plasma.

Corrosão seca: interação plasma-superfície

- **Sinergia** de interação íons energéticos+ radicais reativos em processos na superfície sobre tratamento
- **Parâmetros** importantes da interação:

J_r , J_i , E_i ,
s_r , $\theta_{s,r}$, T_s ,
J_d



Effect of combined chemical reaction and ion bombardment.

Corrosão seca: exemplos práticos de sistemas gás reativo-sólido I

Examples of Plasma Etching Gases and Radicals

ETCHING SPECIES	SOURCE GAS	ADDITIVE	MATERIALS	MECHANISM	SELECTIVE OVER
F	CF_4 C_2F_6 SF_6 NF_3 ClF_3 F_2	O_2 O_2 O_2 None None None	Si	Chemical	SiO_2 Resist
CF_x-film	CF_4 C_2F_6 CHF_3	H_2 H_2 None or O_2	SiO_2/Si_3N_4	Ion-energetic	Si
Cl	Cl_2 Cl_2 CF_3Cl	None C_2F_6 None	undoped Si n-type Si	Ion-energetic Ion-inhibitor	SiO_2
Cl	Cl_2	BCl_3 CCl_4 $CHCl_3$	Al	Ion-inhibitor	Resist SiO_2

Exemplos práticos de sistemas gás reativo-sólido II

Table 10–3. Typical or representative etch plasma etch gases for films used in IC fabrication (After [10.1, 10.4, 10.13, 10.14].)

Material	Etchant	Comments
Polysilicon	SF_6, CF_4	Isotropic or near isotropic (significant undercutting); poor or no selectivity over SiO_2.
	CF_4/H_2, CHF_3	Very anisotropic; nonselective over SiO_2.
	CF_4/O_2	Isotropic; more selective over SiO_2.
	HBr, Cl_2, $Cl_2/HBr/O_2$	Very anisotropic; most selective over SiO_2.
Single-crystal Si	same etchants as polysilicon	
SiO_2	SF_6, NF_3, CF_4/O_2, CF_4	Can be near isotropic (significant undercutting); anisotropy can be improved with higher ion energy and lower pressure; poor or no selectivity over Si.
	CF_4/H_2, CHF_3/O_2, C_2F_6, C_3F_8	Very anisotropic; selective over Si.
	$CHF_3/C_4F_8/CO$	Anisotropic; selective over Si_3N_4.
Si_3N_4	CF_4/O_2	Isotropic; selective over SiO_2 but not over Si.
	CF_4/H_2	Very anisotropic; selective over Si but not over SiO_2.
	CHF_3/O_2, CH_2F_2	Very anisotropic; selective over Si and SiO_2.
Al	Cl_2	Near isotropic (significant undercutting).
	$Cl_2/CHCl_3$, Cl_2/N_2	Very anisotropic; BCl_3 often added to scavenge oxygen.
W	CF_4, SF_6	High etch rate; nonselective over SiO_2.
	Cl_2	Selective over SiO_2.
Ti	Cl_2, $Cl_2/CHCl_3$, CF_4	
TiN	Cl_2, $Cl_2/CHCl_3$, CF_4	
$TiSi_2$	Cl_2, $Cl_2/CHCl_3$, CF_4/O_2	
Photoresist	O_2	Very selective over other films

Corrosão seca - sistema Si+F: processos na superfície

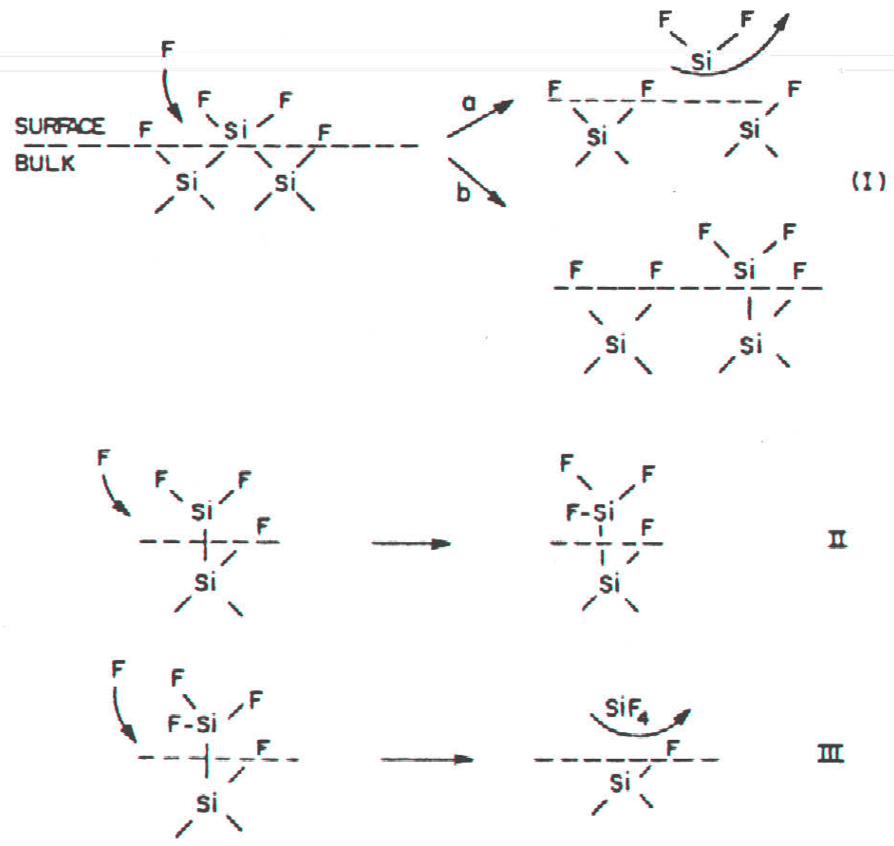


Fig. 7 Proposed mechanism for F-atom reaction with a silicon film leading to the products SiF_2 and SiF_4[13]. Reprinted with permission of the American Physical Society.

Corrosão: química de processos I (volatilidade de produtos)

Table 1
Halogen-, hydride- and methyl-compounds and their volatility for elements and materials of interest in micro- and nano-technology applications

Elements	Fluorides	Boiling temperature (°C)	Chlorides	Boiling temperature (°C)	Bromides	Boiling temperature (°C)	Hydrides, trimethyls	Boiling temperature (°C)
Al	AlF_3	1297 (subl.)	$AlCl_3$	178 (subl.)	$AlBr_3$	263		
As	AsF_3	−63	$AsCl_3$	130.2	$AsBr_3$	221	AsH_3	−55
	AsF_5	−53			$AsBr_5$			
C	CF_4	−128	CCl_4	77	CBr_4	189	CH_4	−164
Cr	CrF_2	> 1300	CrO_2Cl_2	117	$CrBr_2$	842		
Cu	CuF	1100 (subl.)	CuCl	1490	CuBr	1345		
	CuF_2	950	$CuCl_2$	993			CuH	55–60
Ga	GaF_3	1000	$GaCl_3$	201.3	$GaBr_3$	278.8	$Ga(CH_3)_3$	134
Ge	GeF_4	−37 (subl.)	$GeCl_4$	84	$GeBr_4$	186.5	GeH_4	−88.5
In	InF_3	> 1200	$InCl_3$	300 (subl.)			$In(CH_3)_3$	55.7
Mo	MoF_5	213.6	$MoCl_5$	268				
	MoF_6	35	$MoOCl_3$	100 (subl.)				
	MoO_2F_2	270 (subl.)						
	$MoOF_4$	180						
P	PF_3	−101.5	PCl_3	75	PBr_3	172.9	PH_3	−87.7
	PF_5	−75	PCl_5	162 (subl.)	PBr_5	106		
Si	SiF_4	−86	$SiCl_4$	57.6	$SiBr_4$	154	SiH_4	−111.8
Ta	TaF_5	229.5	$TaCl_5$	242	$TaBr_5$	348.8		
Ti	TiF_4	284 (subl.)	$TiCl_4$	136.4	$TiBr_4$	230		
W	WF_6	17.5	WCl_6	346.7				
	WOF_4	187.5	WCl_5	275.6	WBr_5	333		
			$WOCl_4$	227.5	$WOBr_4$	327		

Corrosão: química de processos II
(pressão de vapor)

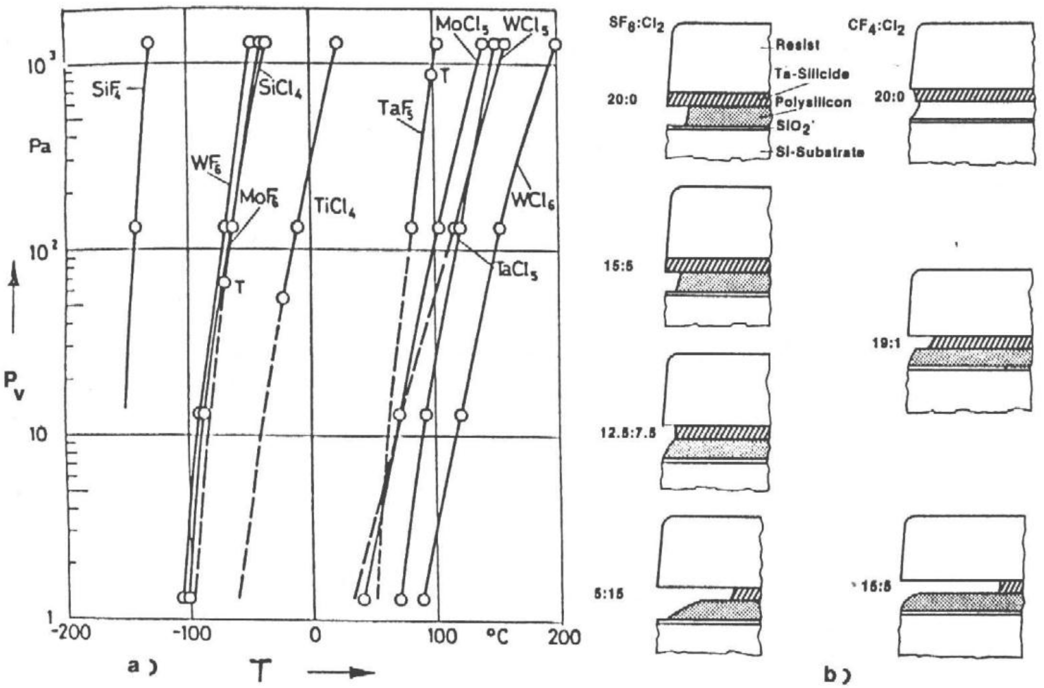


Fig. 17 (a) Vapor pressures of transition metal halides. (b) Polycide etching[31]. Reprinted with permission of Solid State Technology, published by Technical Publishing, a company of Dun & Bradstreet.

Corrosão: evolução de perfil

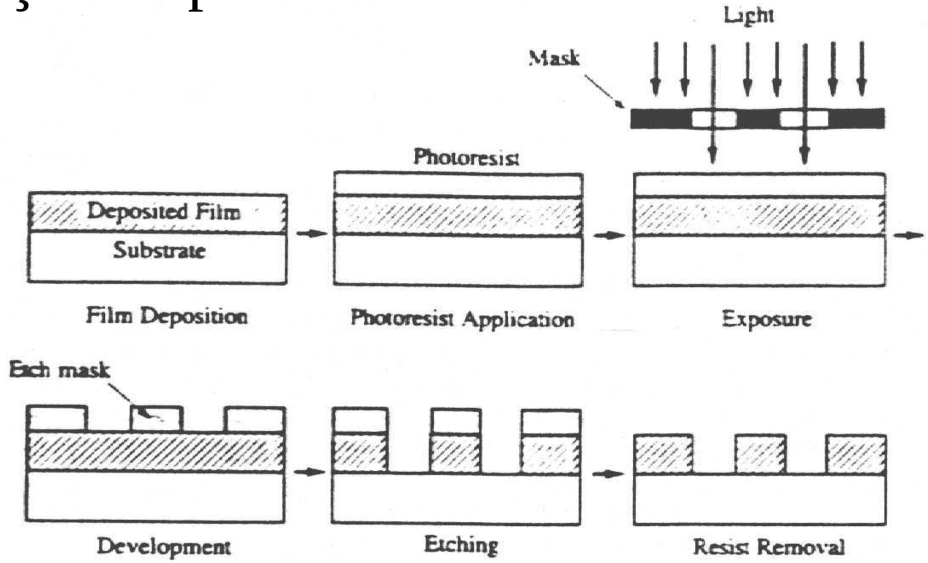


Figure 10–1 General process used in integrated circuit fabrication to define patterned films.

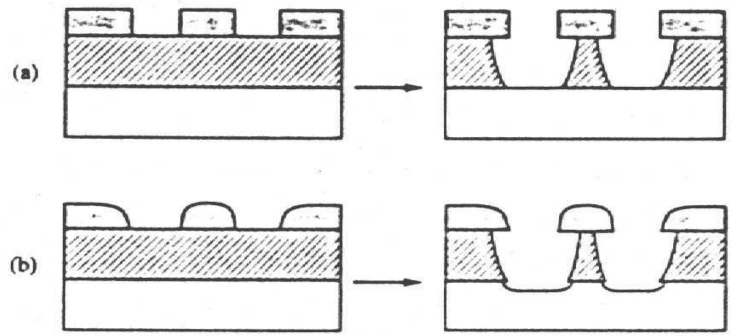


Figure 10–2 Actual etch profiles that can occur. (a) Lateral etching under mask. (b) Rounded photoresist which is further eroded during etching, leading to even more lateral etching. (b) also illustrates etch selectivity.

Corrosão: necessidade de overetch e da seletividade

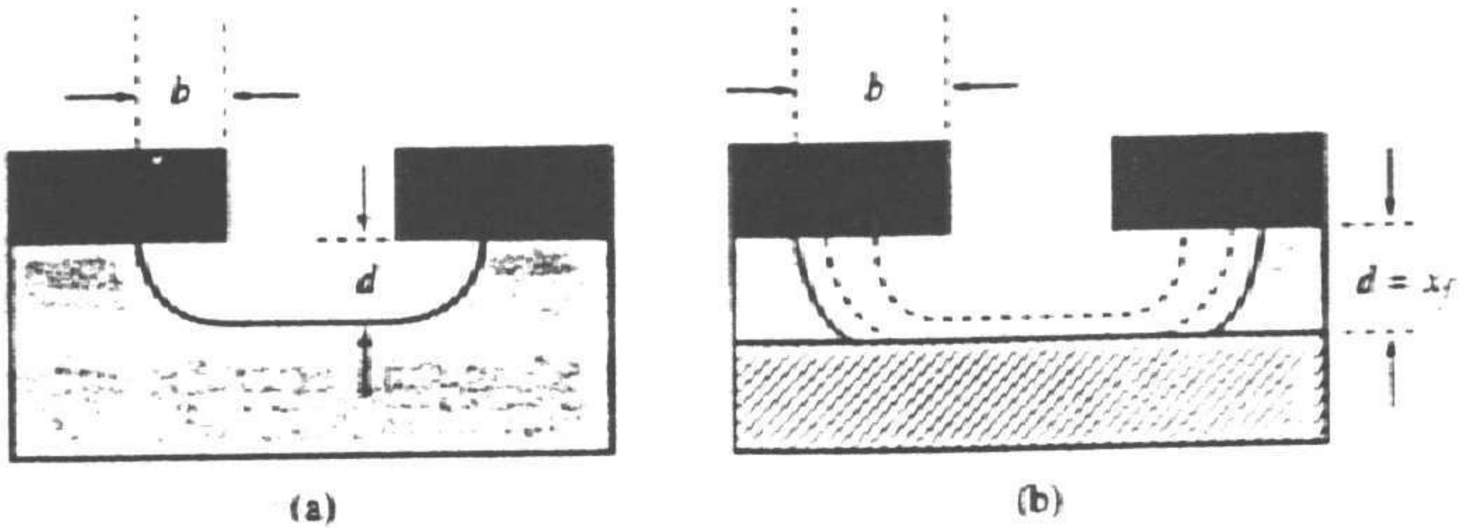


Figure 10–4 Illustration of etch bias and overetch. In (a) the etch bias, b, is shown for a given etch depth, d. In (b), overetching is illustrated where etching is continued even after the etch depth, d, equals the film thickness, x_f, with the result that the etch bias increases.

Perfil de corrosão: grau de anisotropia

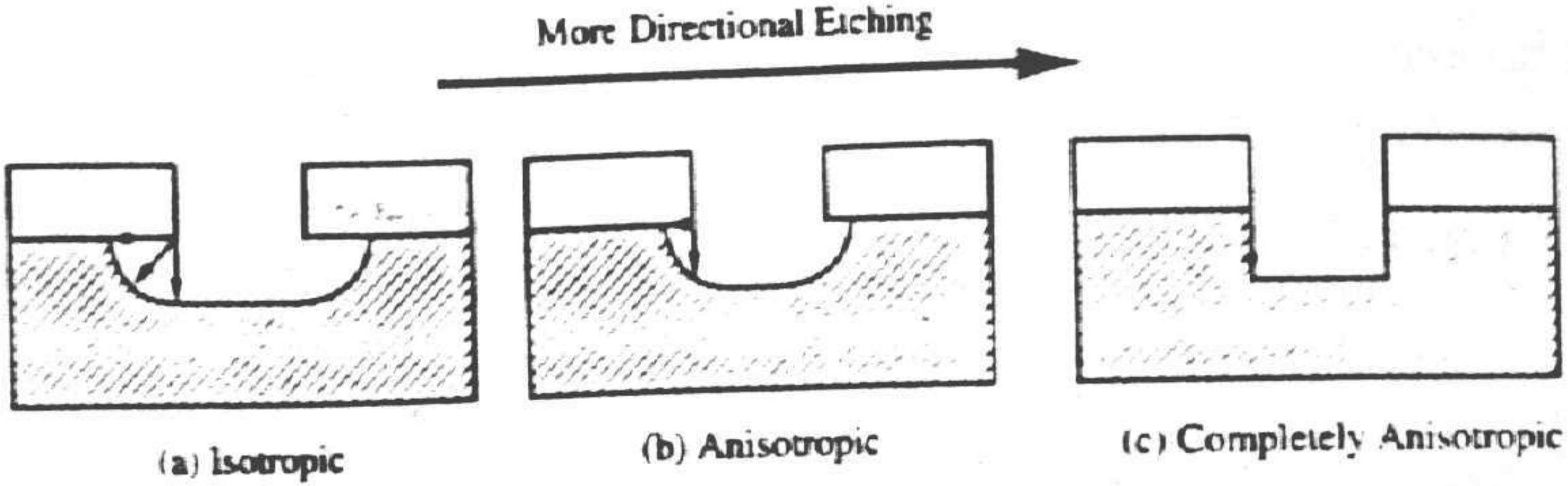


Figure 10–3 Etch profiles for different degrees of anisotropic, or directional, etching: (a) purely isotropic etching; (b) anisotropic etching; (c) completely anisotropic etching.

Processo de corrosão: mecanismos

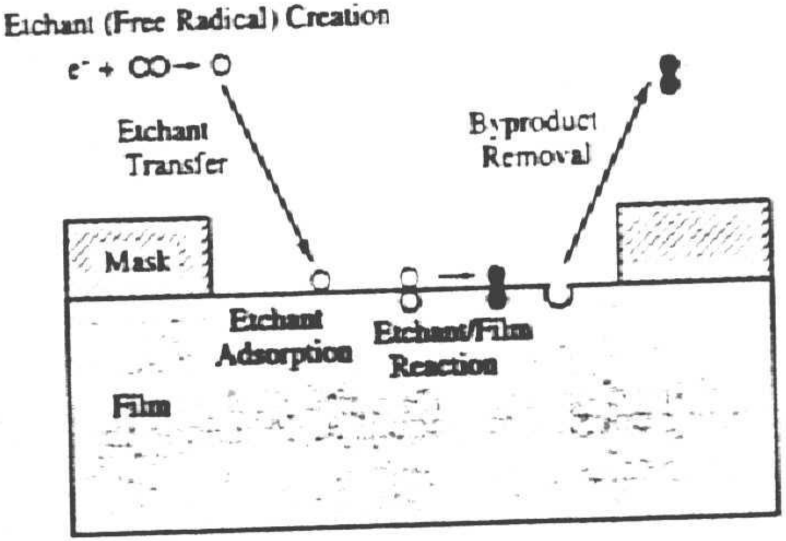


Figure 10–10 Processes involved in chemical etching during plasma etch process.

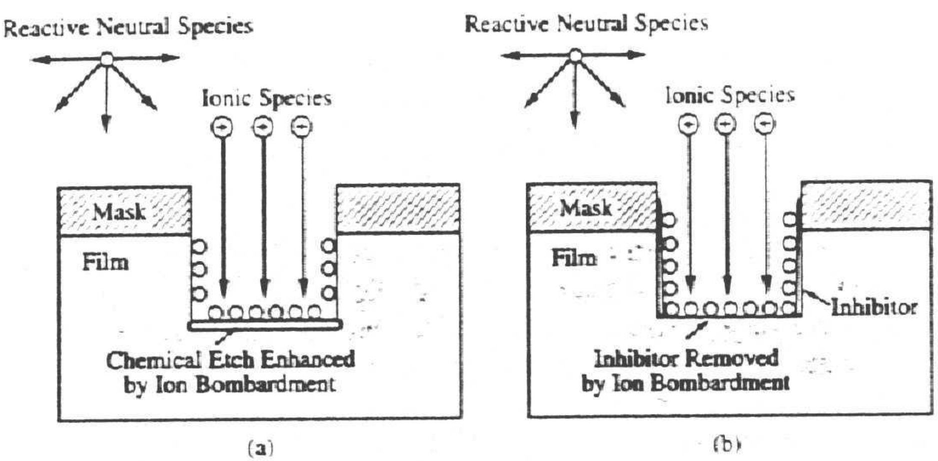


Figure 10–13 Illustration of ion-enhanced etching. In (a) the chemical etch reaction is enhanced by ion bombardment. In (b) an inhibitor is formed which is removed by ion bombardment, allowing chemical etching to proceed. In both cases, anisotropic etching results.

Inibidores de corrosão:

efeitos sobre perfil

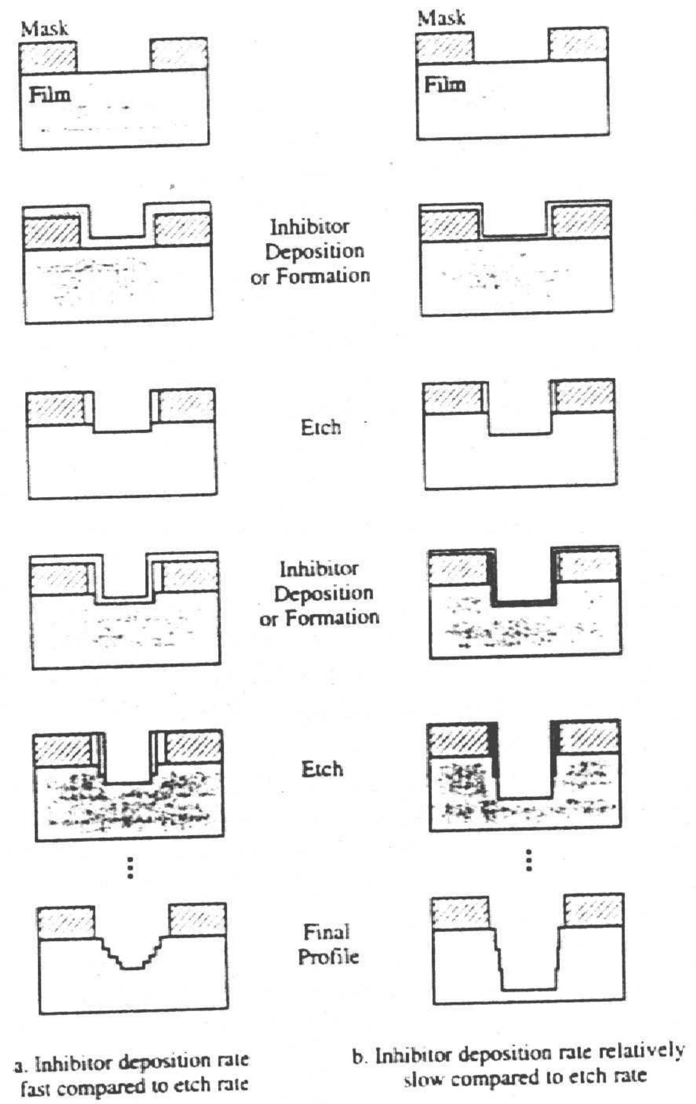


Figure 10–14 Illustration of the effect of the inhibitor deposition rate-to-etch rate ratio on the resulting sidewall slope. The different relative rates of inhibitor deposition and etch rate lead to different slopes of sidewall [10.4].

Perfil de corrosão : efeito de carbofluoretos

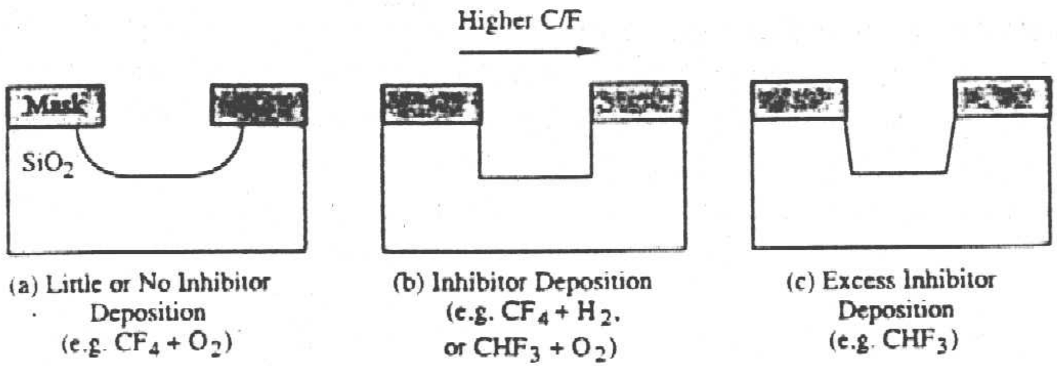


Figure 10–24 Effect of inhibitor deposition on resulting etch profile. The profiles shown assume no mask erosion, which may occur for different etch chemistries. The actual profiles obtained will also depend on the specific etch system and plasma conditions.

Fabricação de *spacers*

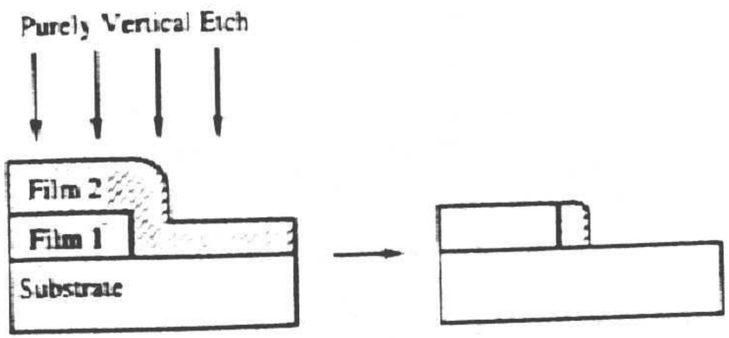


Figure 10–23 Overetching of a film over a step would be required to remove material at corner. In this example, completely anisotropic etching is assumed to emphasize this concept. This phenomenon can be used in producing self-aligned oxide spacers, in which no extra overetching is done so as to intentionally produce the structure at the right.

Bombardeamento iónico: efeitos sobre perfil

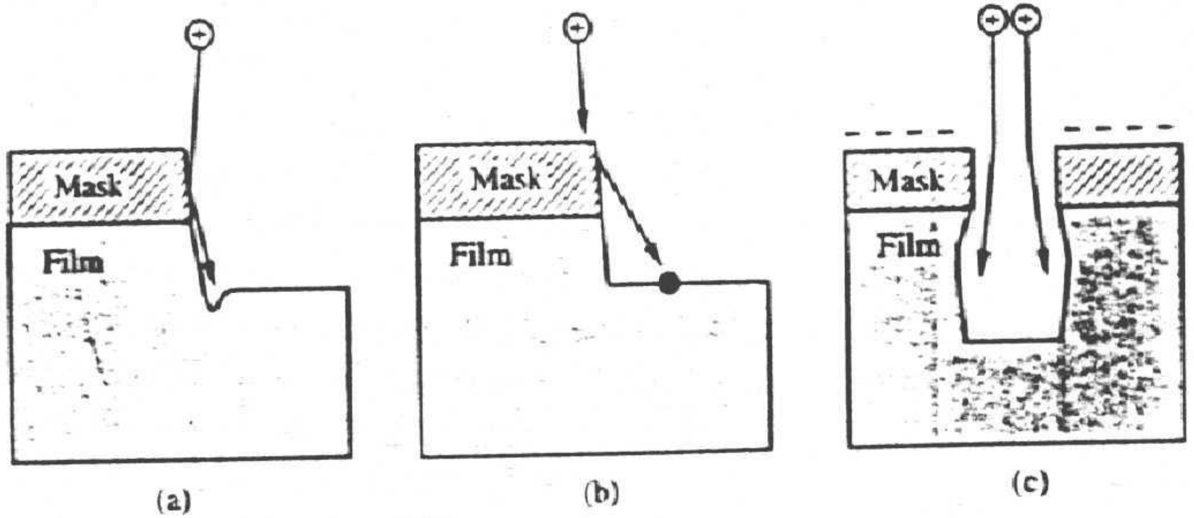


Figure 10–18 Problems associated with sputter etching (or any etching that has a high degree of physical/ionic etching): (a) trenching at bottom of sidewalls; (b) redeposition of photoresist and other material; (c) charging and ion path distortion.