

Uso de Plasmas no Processamento de Materiais

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POSMAT/Unesp-Bauru

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Processamento usando Plasmas

- 1. Introdução
- 2. Morfologia dos Plasmas
- 3. Uso em Filmes Finos
- 4. Conclusões

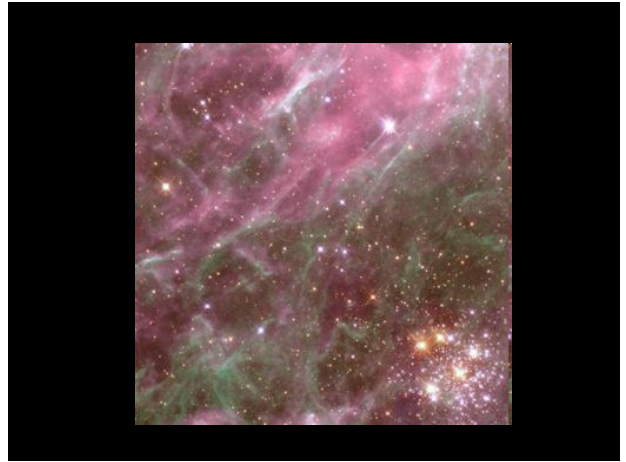
1. Introdução

Plasma

- ◆ O que é ?

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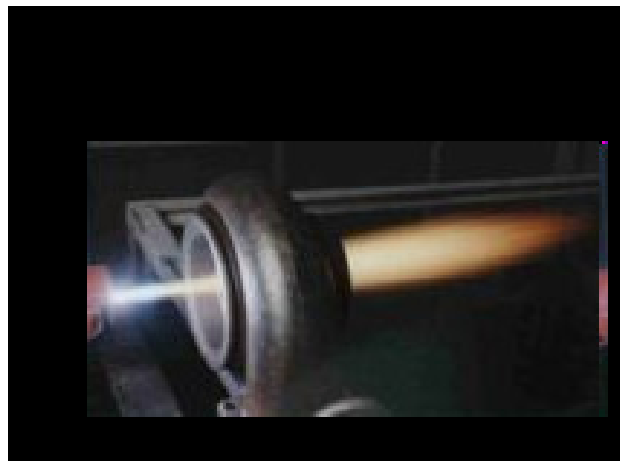
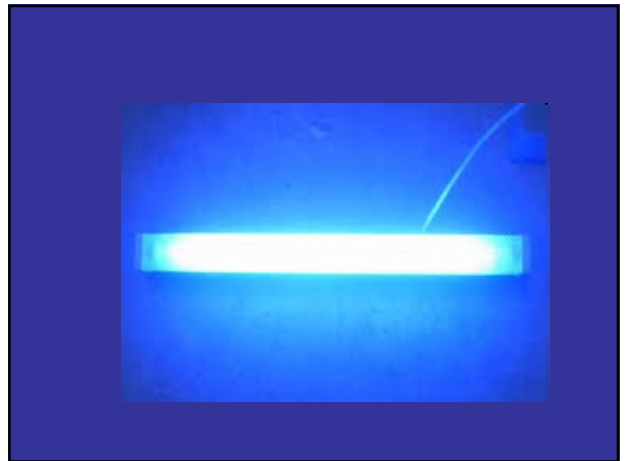




Plasmas naturais

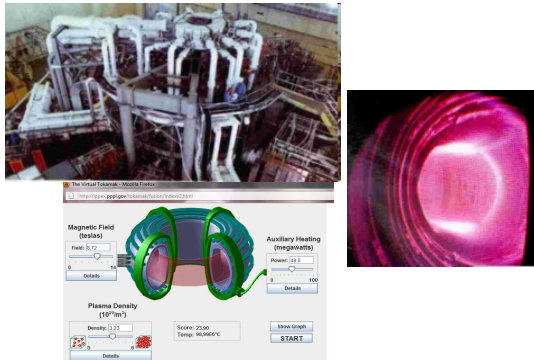
Plasmas “artificiais”

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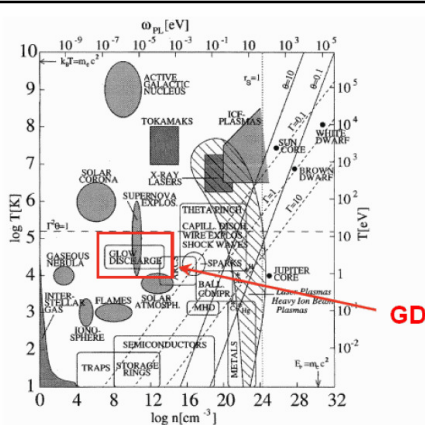
Tokamak

<http://ippex.pppl.gov/tokamak/fusion/indexv2.html>



Plasma

- Características
 - Gás ionizado (diluído)
 - Altas temperaturas
 - Elétrons livres (leves) e íons positivos (pesados)
 - Excelente condutor



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Plasma

- parâmetros importantes
 - Densidade
 - Partículas carregadas - +
 - Partículas neutras
 - Temperatura
 - Energia/velocidade

Plasmas

- ◆ Onde podemos usar ?
 - Esterilização de utensílios cirúrgicos
 - Corrosão seca
 - Cortes de chapas metálicas
 - Geração de altíssimas temperaturas
 - Geração de energia (fusão nuclear)
 - Deposição de filmes finos
 - Criação de padrões em superfícies

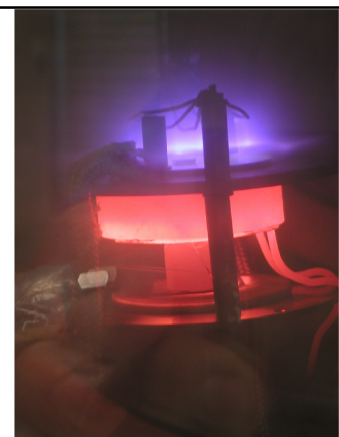
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PECVD

Plasma:

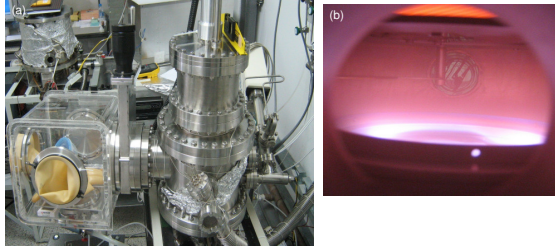
"quebra" moléculas do gás

ativa reações



Reator PECVD - Wikipedia

sputtering reativo (LFS)



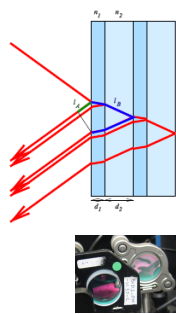
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Aplicações

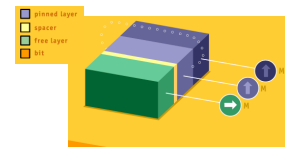
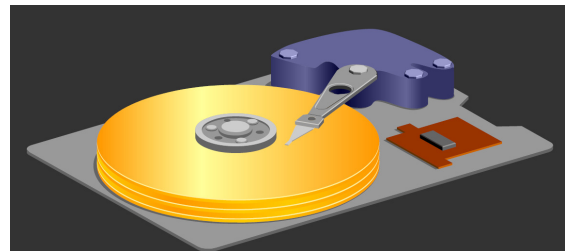
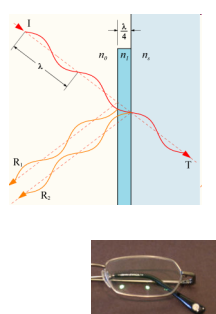
Filmes para recobrimento de vidros arquiteturais



Refletores

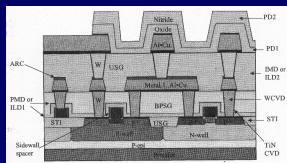


Anti - Refletores



www.research.ibm.com/research/demos/gmr

Variados Tipos de Filmes Finos Utilizados na Fabricação de CIs.

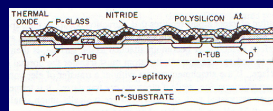


- PD – passivation dielectric
- ILD – interlayer dielectric
- IMD – intermetal dielectric
- PMD – premetal dielectric
- USG – undoped silicate glass
- BPSG – borophosphosilicate glass
- ARC – antireflection coating

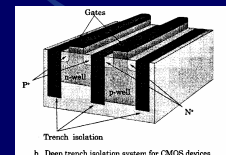
Aplicação de filmes finos dielétricos em circuitos CMOS.

Ioshiaki Doi
FECC e CCS/UNICAMP

Outros Exemplos:



Nitretos e si-poli



Dielétrico para isolamento de 2 dispositivos

- Alguns filmes são usados temporariamente como camada de máscara, enquanto que outros filmes tornam partes do circuito sendo fabricado.

Ioshiaki Doi
FECC e CCS/UNICAMP

Integrando eletrônica e óptica:

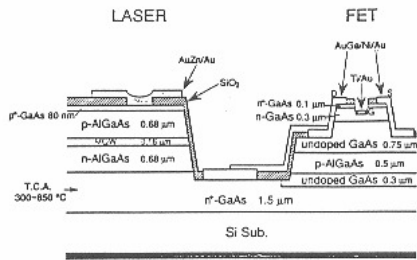


Figure 16. Schematic cross section of a laser diode, and depletion mode FET, monolithically integrated on a Si substrate. [Reprinted by permission, from Photonics Technol. Lett., 4:613 (1992)]

Plasma "Etching" (= corrosão seca) Padrões de superfície

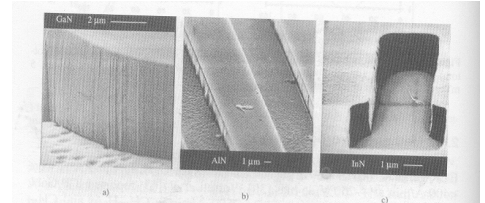


Figure 2.21. SEM micrographs of (a) GaN, (b) AlN, and (c) InN etched in Cl₂-based ICP plasmas

Vantagens do uso de plasmas

- dissociar moléculas a temperaturas relativamente baixas, usando energia de feixe eletrônico
- altas taxas de deposição
- baixas $T_{\text{substrato}}$
- grandes áreas

Plasmas - vantagens

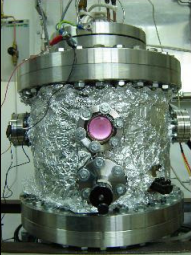
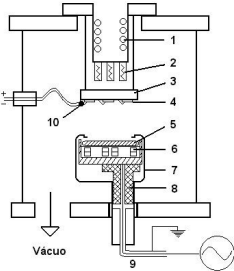
- $T_{\text{PECVD}} \ll T_{\text{CVD Term}}$
- Maior aderência filme-substrato
- Praticamente qq. sólido (!?)
- Decapagem (corrosão/limpeza) seca de superfícies

- Sistemas de deposição relativamente simples

Sistema de Sputtering do LFS



Interior da Câmara de Deposição

1-Circulação de Água Gelada;
2-Resistores de Aquecimento;
3-Porta Substrato;
4-Substratos;
5-Alvo;
6-Ímãs Permanentes;
7-Shield;
8-Isolante;
9-Cabo Coaxial.
10-Termopar

Vácuo

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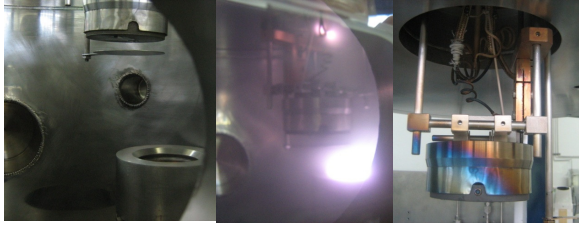
Adaptação do Sistema de Sputtering

K II



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Sputtering



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Low cost of ownership

Highly configurable systems: Process chambers are available as standalone modules, with/without load locks or in cluster configurations on hexapod or square transfer chambers

Clustered PlasmaPro System

Process Modules

ICP	High Density Plasma for high rate etching with low damage
PECVD	Optimised to produce high uniformity dielectric films
RIE	Proven dry etching used throughout the industry
ICP CVD	Produces high density dielectric films at low temperatures with the capability to deposit onto damage sensitive surfaces
PVD	Magnetron sputtering tool capable of reactive or physical processes



PlasmaPro100 ICP CVD

PlasmaPro100

Descarga Luminescente ow discharge

ensures uniform wafer temperatures & optimised film properties




Excellent uniformity, good quality, high rate films, with control of film properties

PlasmaPro100

ICP & RIE Etch Process Modules


High density plasma etching

ICP

An inductively coupled plasma (ICP) source produces a high density of reactive species at low pressure. Substrate DC bias is independently controlled by a separate RF generator, allowing control of ion energy according to process requirements.

- The ICP module delivers reactive species to the substrate, with a uniform high conductance path through the chamber, allowing a high gas flow to be used while maintaining low pressure
- Compatibility with 50mm to 200mm wafers or carriers ensures that you have the ability to develop devices that can be taken to production using the same chamber hardware
- Electrodes available for temperatures from -150°C to +400°C – offers single system flexibility
- captons
- Electrostatic shielding delivers reduced ion damage and reduced capacitive coupling
- Chamber wall heating and lines reduce cleaning requirements, and increases uptime
- Electrostatic chuck or mechanical clamping with helium, backside cooling

RIE



*High aspect ratio microvia etching only (see University of Cornell Nanoscale Science and Technology facility)

Mas...

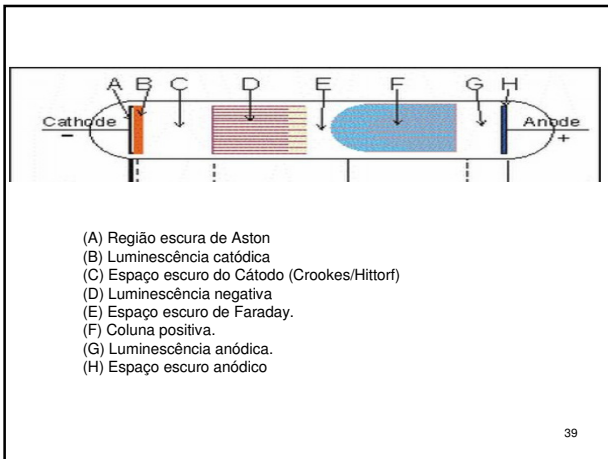
o que é um plasma ...

... ? afinal ?....

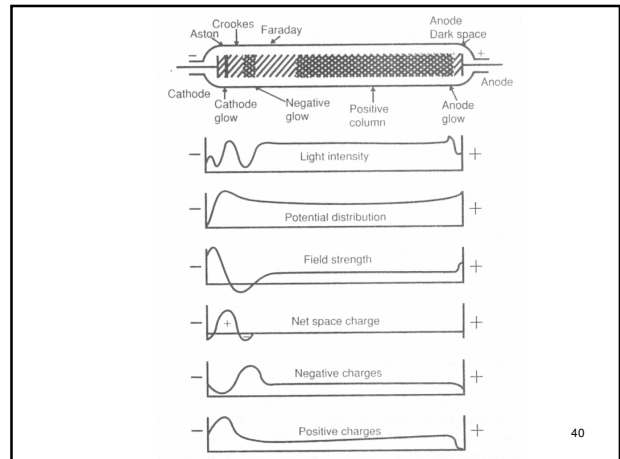
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2. Morfologia dos Plasmas

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dissociação molecular por impacto eletrônico

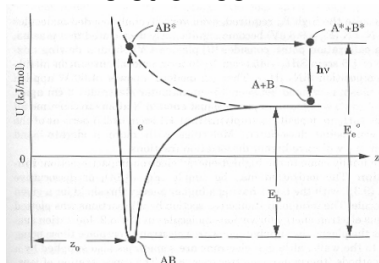


Figure 9.1 Internal energy, U , vs. bond length, z , during electron-impact dissociation of the molecule AB . z_0 is the relaxed bond length, the dashed line corresponds to the antibonding orbital, and $h\nu$ represents photon emission in relaxation of the excited-state radicals A^* and B^* .

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dissociação molecular por impacto eletrônico

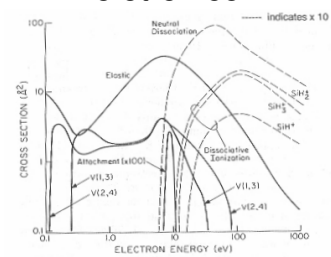


Figure 9.2 Electron-impact reactions of silane gas (SiH_4). Vibrationally excited states are denoted by $V(i, j)$. $1 \text{ \AA}^2 = 10^{-20} \text{ m}^2$. (Source: Reprinted from Ref. 12 by permission.)

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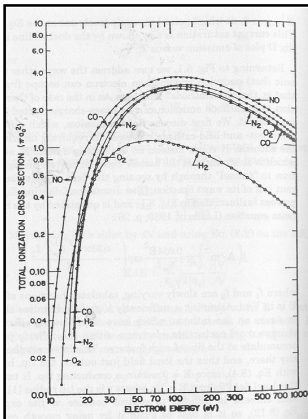


Figure 8.3 Ionization cross sections of various small molecules, normalized to the projected area of the H atom, $\pi a_0^2 = 0.85 \times 10^{-16} \text{ cm}^2$, based on its Bohr radius, a_0 . (Source: Reprinted from Ref. 6 by permission.)

- Colisões entre elétrons e gases
 - Seção de choque
 - Potencial de ruptura

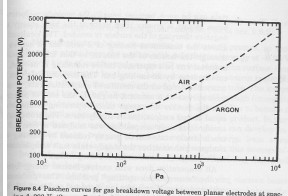


Figure 8.4 Paschen curves for gas breakdown voltage between planar electrodes at spacing 8.253 K. (Source: Reprinted from Ref. 6 by permission. Pressure units changed to Pa.)

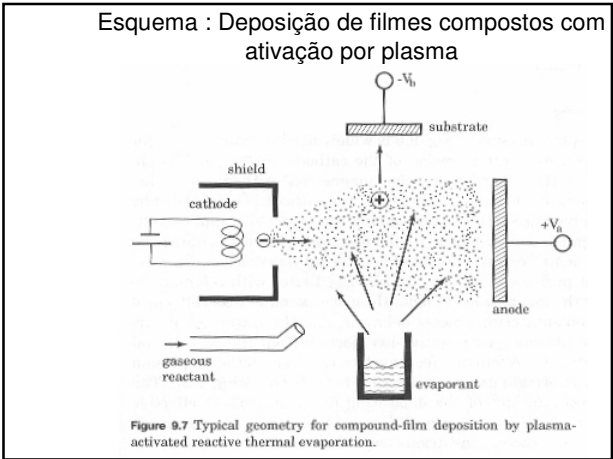
3. Uso em Filmes Finos

- 3.1 PAMBE , PECVD (glow discharge)
- 3.2 Sputtering

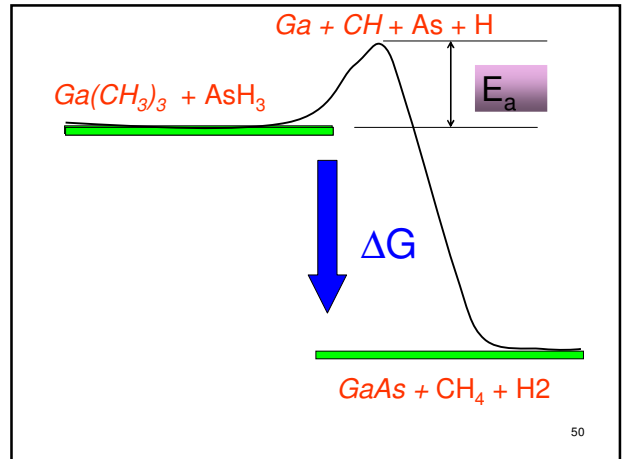
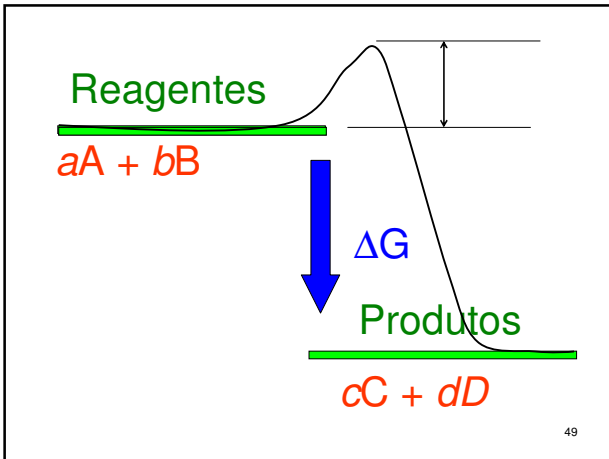
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PAMBE / PECVD

- Plasma assisted MBE
- Plasma enhanced CVD



PECVD



PECVD

Plasma:
"quebra" moléculas do gás
ativa reações

Reator PECVD - Wikipedia

Pirólise x Plasma

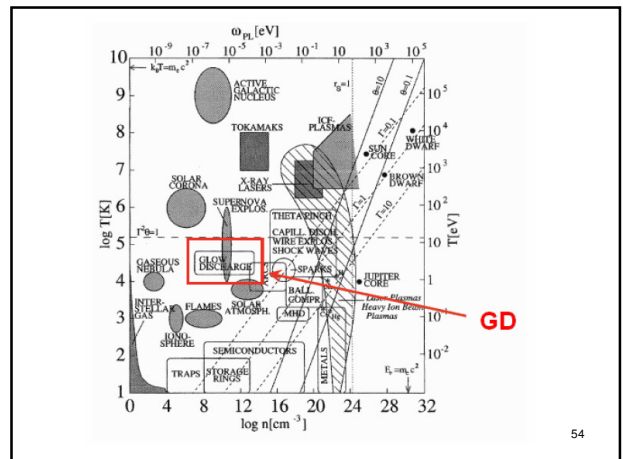
- Pirólise
 - Energia térmica
 - Alta pressão (transmissão de calor)
- Plasma
 - Energia elétrica
 - Baixa pressão

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Transferência de Energia para a Deposição Através do Plasma

- Aceleração dos elétrons livres no campo aplicado
- Reações de impacto eletrônico com moléculas de gás, => íons, elétrons, radicais livres, moléculas em estado excitado.
- Difusão destas partículas energéticas para fora do plasma na direção das paredes da câmara e da superfície dos filmes
- A aceleração dos íons para as paredes e para o filme pelo "campo de bainha" ("sheath field") próximo a eles.

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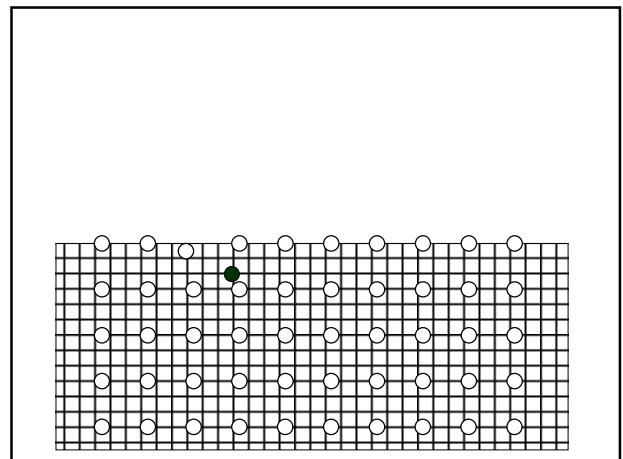
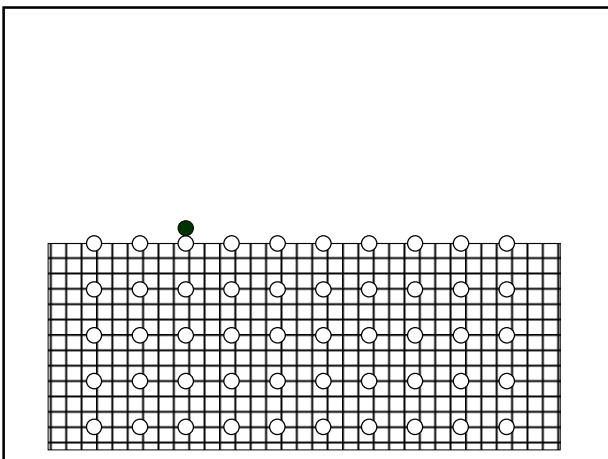
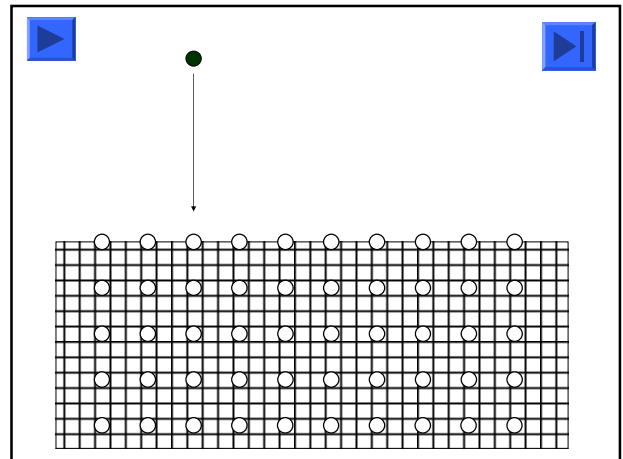


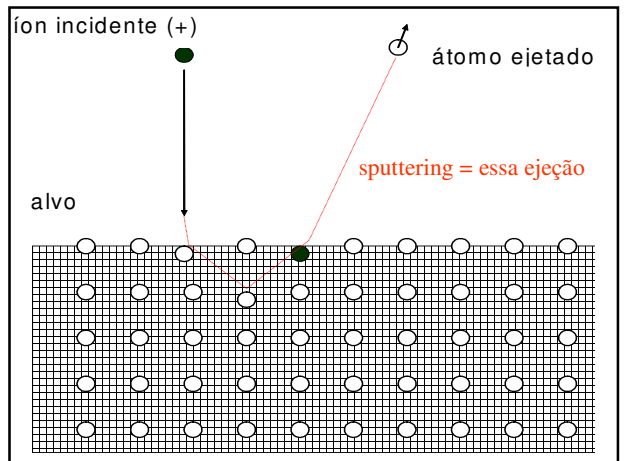
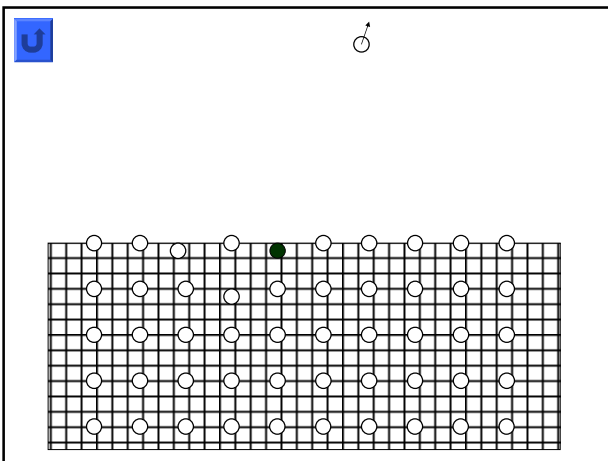
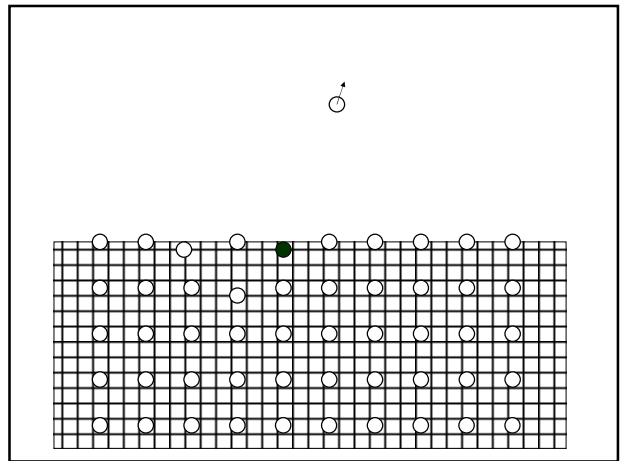
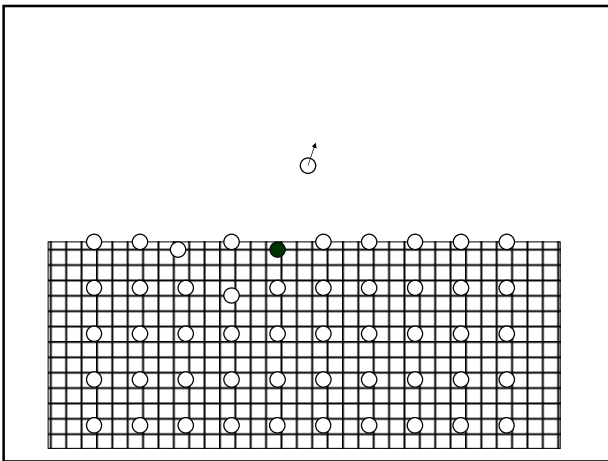
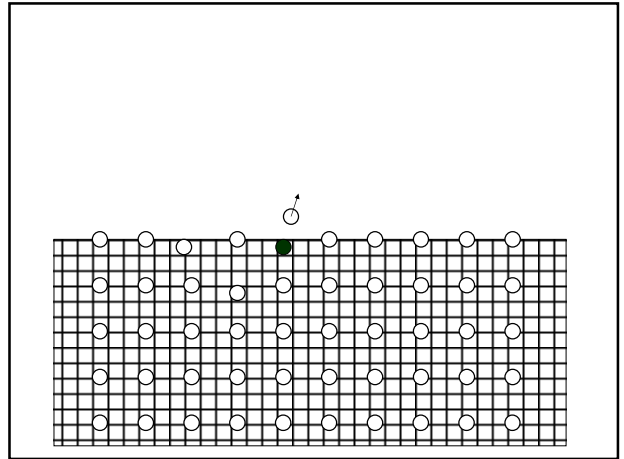
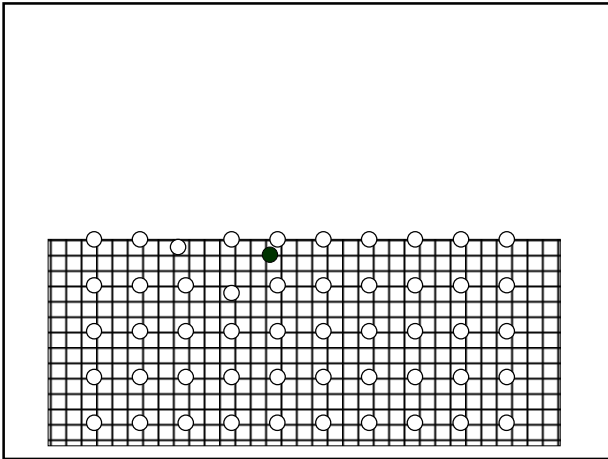
3.2 - Sputtering

■ ???!

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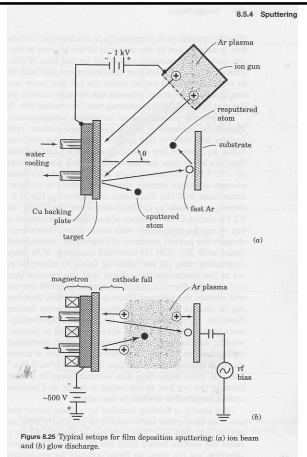
Mecanismo do sputtering



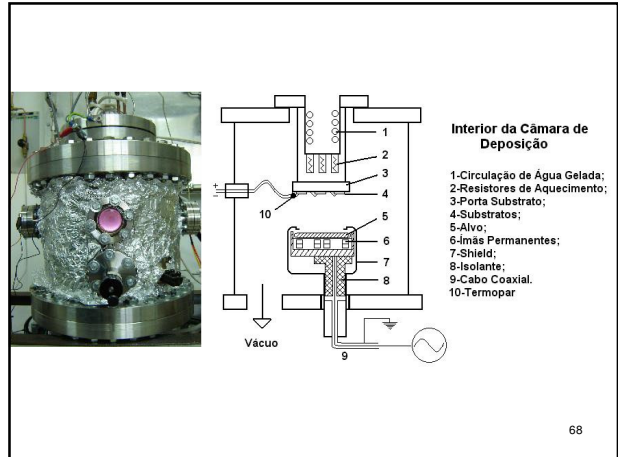


Sputtering

- Ion Beam
- Glow Discharge



[D.L. Smith]



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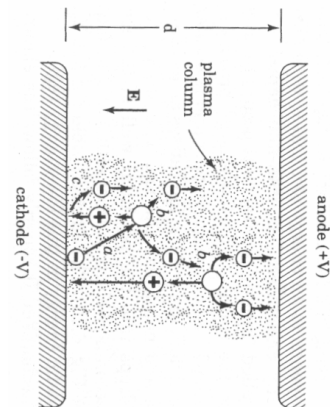
Etapas Sputtering com Descarga Luminescente

1. Geração de um plasma (por ddp em gás)
2. Aceleração dos íons⁺ para alvo (cátodo)
3. Ejeção átomos do alvo (transf. mom. lin.)
4. Difusão de átomos ejetados pelo gás
5. Deposição (energética) em substrato

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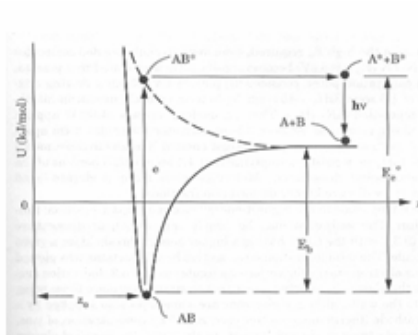
1. Geração de um plasma (por ddp em gás)



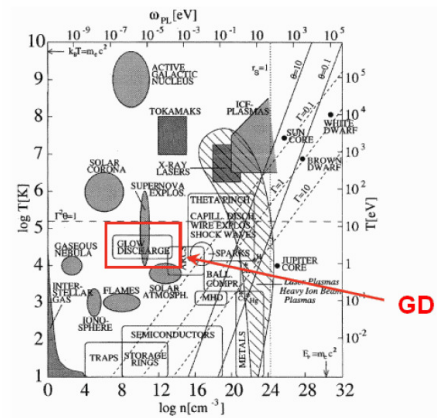
[D.L. Smith]

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Ionização / dissociação do gás por impacto eletrônico



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Ponto Importante

plasma do sputtering:

$T(\text{gás})$ - baixa

$T(\text{elétrons e íons})$ - alta ($\sim 10.000\text{K}$)

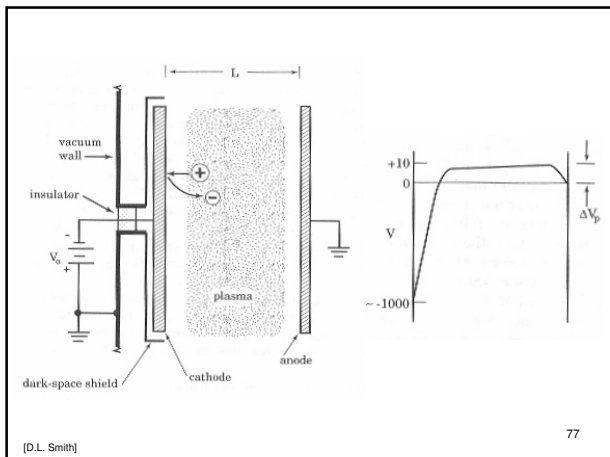
. diferença de $T \Leftrightarrow$ injeção energia elétrica

$$T_{\text{média}} \sim T_{\text{gás}} \text{ (plasma frio)}$$

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2. Aceleração dos íons⁺ para alvo (cátodo)

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[D.L. Smith]

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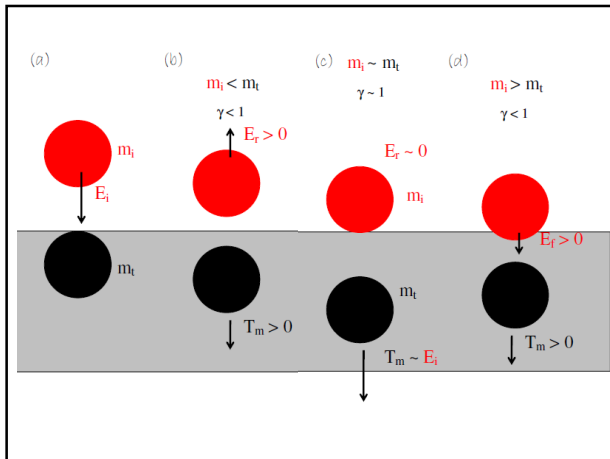
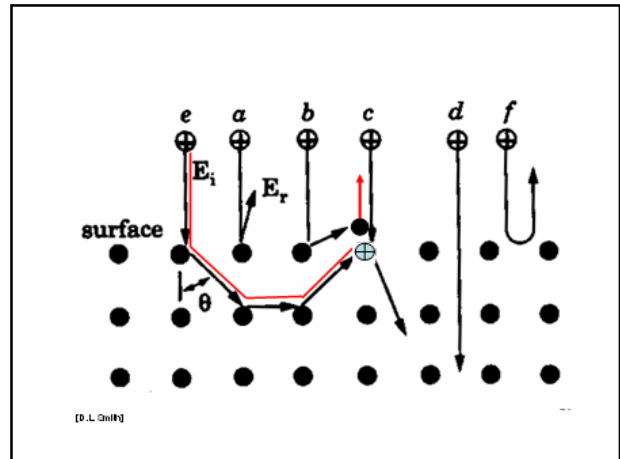
Ponto Importante

- A bainha de carga espacial acelera os íons positivos para a superfície do alvo. Os íons atingem estas superfícies com energias de 10 a 1000eV.

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3. Ejeção átomos do alvo (transferência de momento linear)

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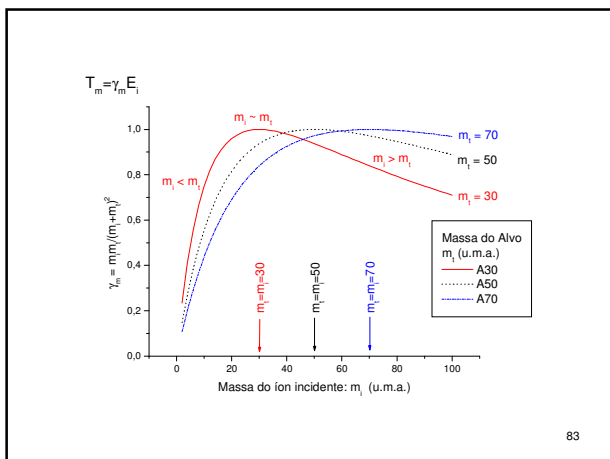


Energia de Recuo

$$T_m = \left(\frac{4 \cdot m_i \cdot m_t}{(m_i + m_t)^2} \right) E_i = \gamma_m \cdot E_i$$

E_i – Energia cinética do íon incidente
 T_m – Energia de recuo do átomo do alvo
 m_i – massa do íon incidente
 m_t – massa do átomo do alvo
 γ_m – fator de acoplamento energético

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Quantos átomos são ejetados
da superfície para cada
íon incidente ?

Sputtering Yield

$$Y_S = \frac{4.2\alpha S_n(\epsilon)}{\Delta_S H}$$

$\Delta_S H$ - calor latente de sublimação

S_n - potencial de frenagem nuclear

ϵ - energia do íon incidente

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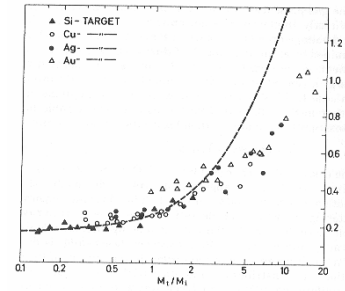
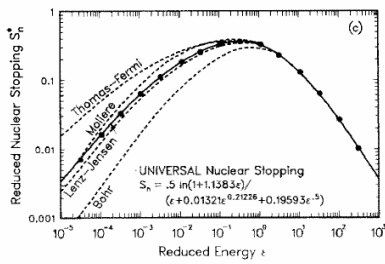


Figure 8.28 The factor α of Eq. (8.37). Dashed line was calculated from transport theory [60], and data points from measured sputtering yields for the targets indicated and ions of various masses, M_i . (Source: Reprinted from Ref. 58 by permission.)

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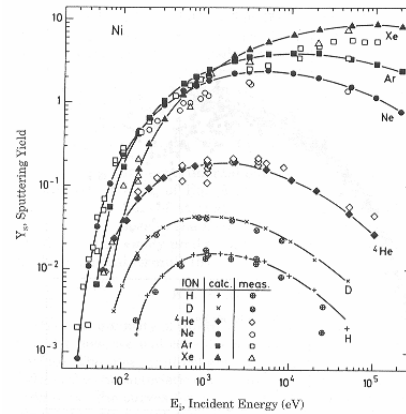


Figure 8.27 Measured sputtering yield for Ni and TRIM code calculation for various ions impinging perpendicularly. (Source: Reprinted from Ziegler (1985) by permission of Martinus Publishers Co., copyright © 1985 by Permission from I.

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Quais as energias dos átomos ejetados ?

Distribuição de Energia dos Átomos Ejetados (Sputtering)

E_t = energia cinética do átomo "espirrado"

E_b = energia de ligação

$$\frac{dN}{N} = \frac{2E_t \cdot E_b}{(E_t + E_b)^3} dE_t$$

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Filmes por sputtering

- Metais
=> ligações não direcionais
- Semicondutores
=> ligações covalentes
=> contaminantes: crítico

Desvantagens Potenciais Problemas

- Criação de defeitos (energia excessiva)
- Plasma => contaminação (das paredes/gás)
- Contaminação do alvo / instabilidade
(compostos, no sputt. reativo)

Possíveis Soluções

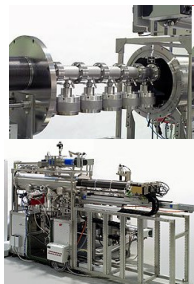
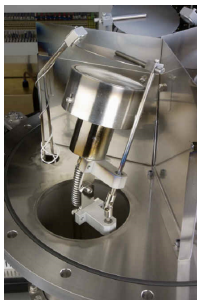
- Temperatura de substratos mais altas
(annealing dos defeitos durante o crescimento)
- Uso de sistemas com menor pressão residual (mais limpos)
- Fluxo de gás inerte direto sobre o alvo / isolamento do alvo (diminui poisoning)
- Sistema magnetron
(campo magnético => plasma confinado mais próximo do alvo)

Vantagens...

- Sólidos podem ser vaporizados (a baixa $T_{médica}$)
- Energia alta favorece aderência
- Uso de energia elétrica em vez de térmica
- Material do alvo + gás reativo => composto ..
- Sistema relativamente simples...

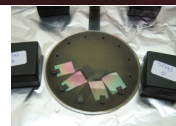
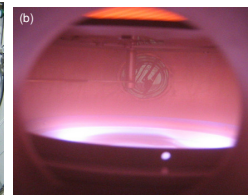
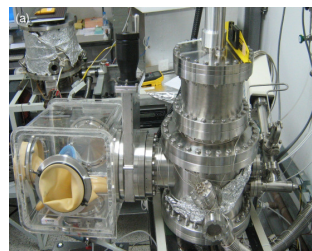


Sistemas de Sputtering



www.dca.fi.uh/%20sputtering.htm

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4. Conclusões

- Plasma – gás ionizado
- Energia elétrica x térmica
- Sputtering – ejeção transferência de momento linear

Próxima aula : corrosão a plasma / padrões

