IV SEFiSMαT

Crescimento de filmes semicondutores usando plasmas frios

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POSMAT

Física

Semicondutores
Plasmas
Crescimento de Filmes

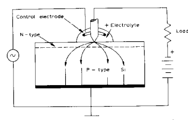
Física

Semicondutores
Plasmas
Crescimento

Semicondutores

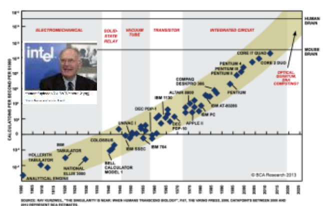
O que são?
Por que são importantes?

Bardeen Shockley
Brattain
(1951 => Nobel:1956)

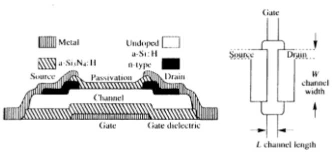


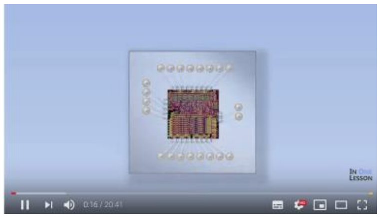
"There is enough room in the botton"

Richard Feynman



Transistor de Filme Fino





11

LEDs

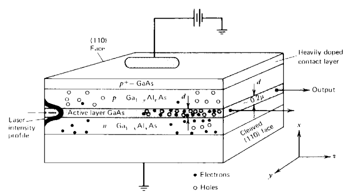
13

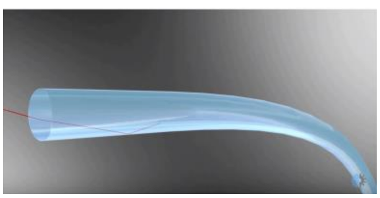
Comunicações / Internet / Celular

Lasers Semicondutores / LEDs

14

Laser semicondutor: GaAs/GaAlAs





16

17

Transistor de GaN de alta potência: celular e radar

18

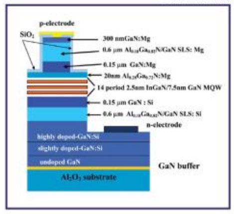
LEDs Azuis / GaN

The Nobel Prize in Physics 2014
Isamu Akasaki, Hiroshi Amano, Shuji Nakamura

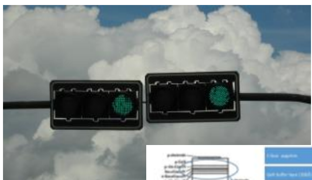
19

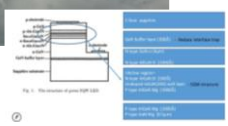
Laser Semicondutor Azul de Cavidade Vertical

Figure 1a: Sheffield Laser diagram
Courtesy: Sheffield University



26 III-Vs REVIEW THE ADVANCED SEMICONDUCTOR MAGAZINE VOL 18 - NO 1 - FEBRUARY 2005





Física

Semicondutores
Plasmas
Crescimento

23

Plasmas

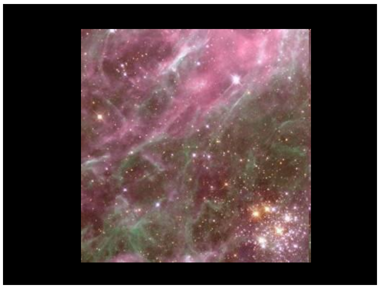
O que são?
O que têm de interessante?

24

Plasmas

- O que são ?

25



↑ Plasmas naturais

↓ Plasmas “artificiais”

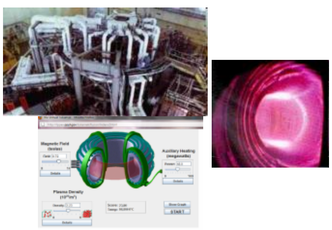
30

32

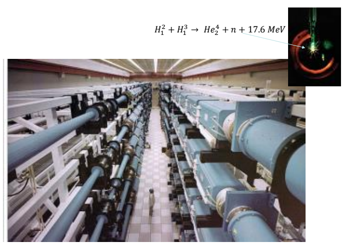
Propulsão a plasma

Tokamak

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

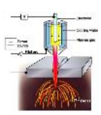


$$H_1^2 + H_1^3 \rightarrow He_2^4 + n + 17.6\ MeV$$

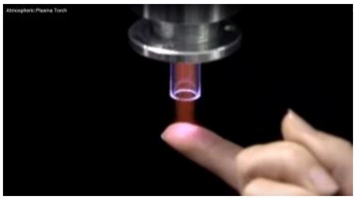


NOVA laser
Inertial Confinement Fusion ICF

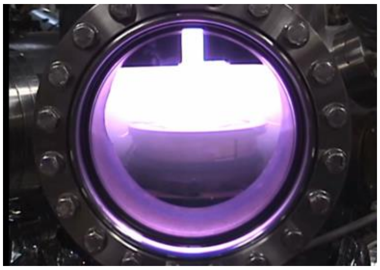
35

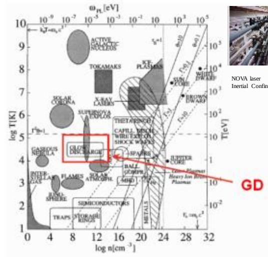


36



37

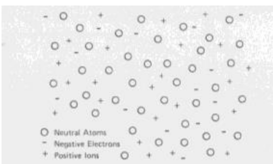




NOVA laser
Inertial Confinement Fusion ICF

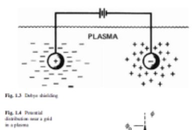
39

Gás ionizado / Plasma



[B. Chapman. Glow Discharge Processes, Wiley, 1980]

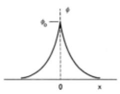
40



$$\epsilon_o \frac{d\phi}{dx} = -e(n_i - n_e)$$

Poisson

$$\lambda_D = \left(\frac{\epsilon_o k_B T_e}{n_\infty e^2}\right)^{1/2}$$



F. Chen. Introduction to Plasma Physics

41

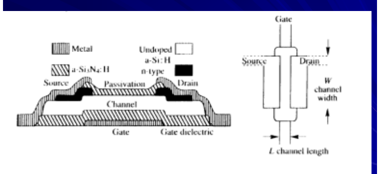
Física

Semicondutores

Plasmas

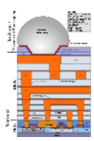
Crescimento de Filmes

42



Filmes Semicondutores

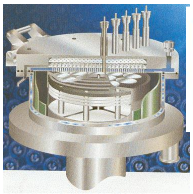
- Tamanho
- Economia
- Pureza
- Arquitetura



Principais Técnicas de Crescimento

45

CVD – Deposição de Vapores Químicos

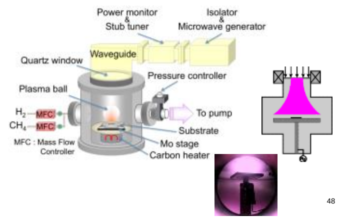


Crescimento de Filmes

Qual a união entre a física de semicondutores e a física de plasmas?

47

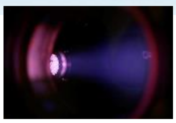
CVD Assistido por Plasma (PECVD)

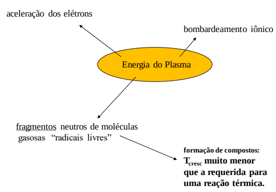


48

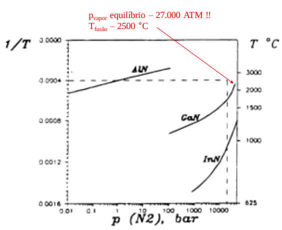
MBE – Epitaxia por Feixes Moleculares

MBE assistido por plasma





51



[Porowski et al]

MBE & CVD

- Alto controle / alta qualidade
- $$$!!

Alternativa:
técnica de sputtering

54

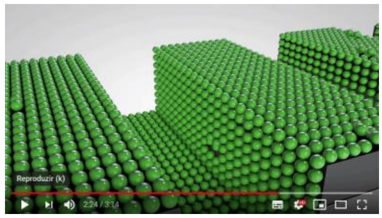
Representação idealizada do processo de sputtering

55

Sistemas de Sputtering

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

56



Corrosão a plasma => *plasma etch*

57

Descarga Luminescente (GD)

Grau de ionização ~ 1/10.000

n ~ 10^9 elétrons / íons (cm^{-3})

T(gás) – baixa (300K)

T(elétrons) – alta (~20.000K)

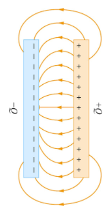
. diferença de T ⇔ injeção energia elétrica

$T_{média}$ ~ $T_{gás}$ (plasma frio)

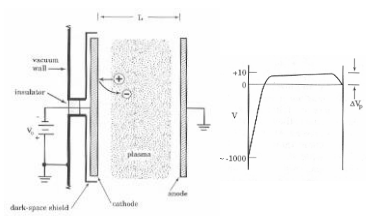
58

Sputtering

Perfil de Potencial do Plasma

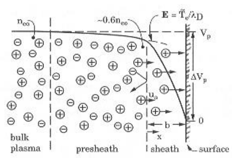


60



61

[D.L. Smith]



[D.L. Smith. Thin Film Deposition. 1995]

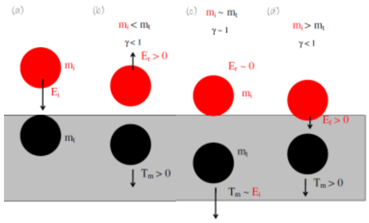
62

Aceleração dos íons

- 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.

63

Mecanismo do sputtering



Energia de Recuo

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

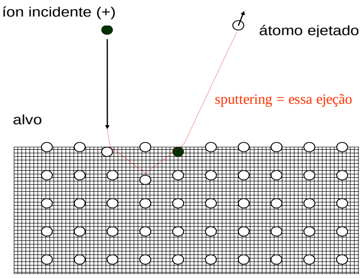
E_i – Energia cinética do íon incidente

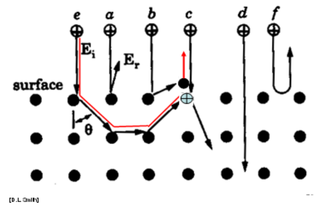
T_m – Energia de recuo do átomo do alvo

m_i – massa do íon incidente

m_t – massa do átomo do alvo

γ_m – fator de acoplamento energético





Quantos átomos são ejetados da superfície para cada íon incidente ?

Sputtering Yield

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

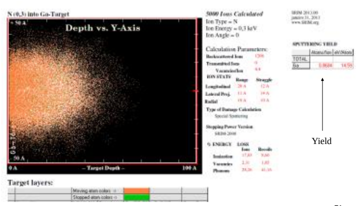
$\Delta_S H$ - calor latente de sublimação

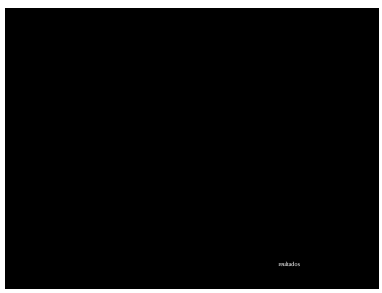
S_n- potencial de frenagem nuclear

ε - energia do íon incidente

Monte-Carlo simulation (SRIM program (Ziegler & Biersack))

N (300eV) => Ga (target)





Sputtering

Excelente para deposição de filmes de metais e ligas metálicas

73

Sputtering

Como depositar semicondutores compostos?

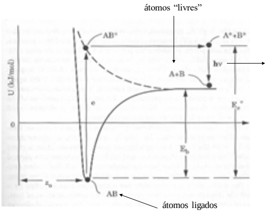
74

Sputtering / Sputtering Reativo

Quais os mecanismos envolvidos ?

75

dissociação do gás
=> impacto eletrônico



76

Sputtering Reativo

- plasmas usados com **duplo** propósito
  - Produção de átomos por impacto (sputtering)
  - Quebra das moléculas (ativação por e^-)

77

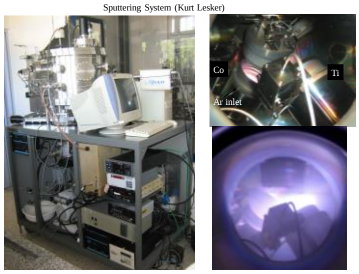
- Nossos resultados (TiO_2, GaN)
- Conclusões

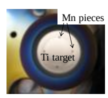
Filmes TiO_2

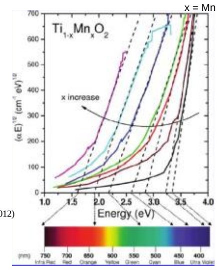
sputtering reativo

79

Sputtering System (Kurt Lesker)



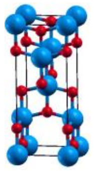




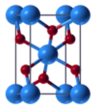
André L. J. Pereira et al.
J. Phys. Chem. V.116, 8753 (2012)

81

Fases principais TiO2



anatase



rutilo

Deposition Parameters – TiO_2 anatase

- Target: Ti (5N), planar magnetron, 75 mm
- Power – 120 W (RF)
- Process pressure: 5.0 x 10^{-3} torr ($Ar+O_2$),
- Residual pressure: $2x10^{-6}$ torr (~H_2O)
- Substrates: a-SiO_2, Ti, $LaAlO_3$, Si (100), Al_2O_3
- Substrate temperature: 300 °C , grounded
- Argon flux: 40 sccm
- Thickness: 100 – 500 nm (dh/dt ~ 0.5 Å/s).

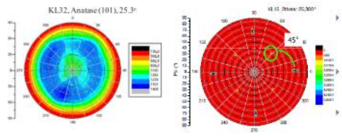
XRD – pole figures

TiO_2 Film – substrate influence on structure

Amorphous (silica) substrate

LAO substrate

TiO2 – anatase (101)



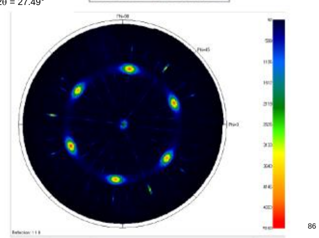
Deposition Parameters – TiO2 rutile

- Target: Ti (5N), planar magnetron, 75 mm
- Power – 180 W (RF)
- Process pressure: 2.0 x 10^{-3} torr,
- Residual pressure: $2x10^{-6}$ torr (~H_2O)
- Substrates: a-SiO_2, $LaAlO_3$, Si (100), Al_2O_3
- Substrate temperature: 450 °C , grounded
- Argon flux: 40 sccm

XRD – pole figures

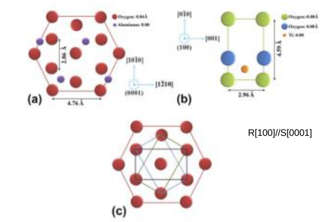
R (110)
2θ = 27.49°

R[100]//S[0001]



M.R. Bayati et al.: Low-temperature processing and control of structure and properties of TiO_2/c-sapphire epitaxial heterostructures

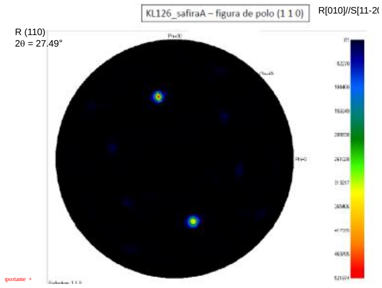
J. Mater. Res., Vol. 28, No. 13, Jul 14, 2013



R[100]//S[0001]

R (110)
2θ = 27.49°

R[010]//S[11-2(

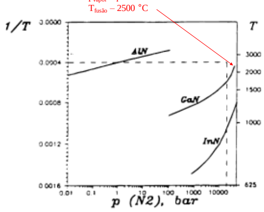


Principais Resultados TiO_2

- Dopagem com Mn
  => grande variação do bandgap
- Potência / substrato / temperatura
  => epitaxias: anatase$^-$ rutilo$^+$

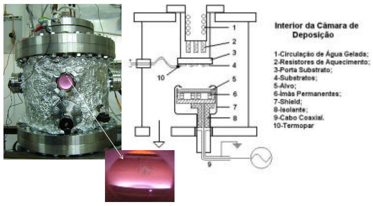
Filmes de GaN

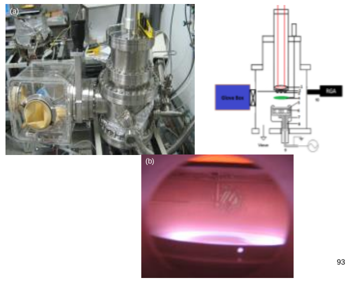
p_{vapor} equilíbrio ~ 27.000 ATM !!
$T_{fusão}$ ~ 2500 °C



[Porowski et al]

Câmara de Sputtering Reativo – Unesp / Bauru



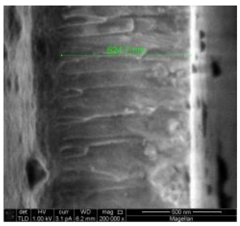


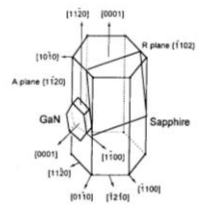
GaN - deposition details

- Ga target (T_m = 29,6 °C): liquid / solid.
- High N concentration (=> GaN stoichiometry).
- Gas flow Ar (10 sccm) / N_2 (10 sccm) => highly poisoned target regime.
- N_2 discharge previous to deposition (15 min).
- Low power (45W/70 cm^2 target).
- Relatively high N_2 pressure (1.5x10^{-2} torr).
- Epitaxy tests:
  - substrate materials and substrate temperatures.

SEM cross section, GaN – reactive sputtering

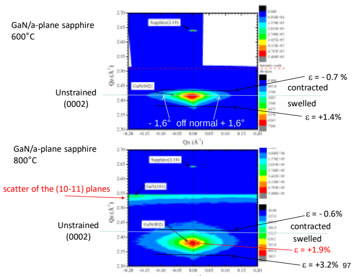
Sapphire, a-plane, 600°C, 10sccm Ar/10 sccm N_2, 45W, dh/dt ~ 1 Å/s



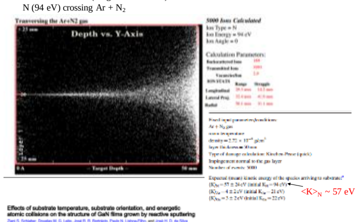


GaN	Al_2O_3	in plane	mismatch
(0001)/(11-20)		[1-100]//[-1100]	f = -0.4%
(0001)/(0001)		[11-20]//[10-10]	f = 13.8%

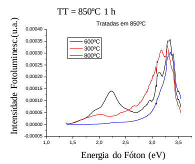
Ref: B. Gil, in: "*GaN - II, Semiconductors and Semimetals*", Vol. 57, (eds) Pankove / Moustakas.



Simulation SRIM (Ziegler & Biersack)
N (94 eV) crossing Ar + N_2



GaN – nc - sputtering

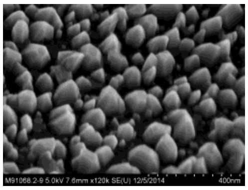


[medida: F. Iikawa, Angela Unicamp]

Nanocolunas de GaN
sputtering reativo

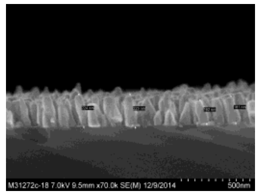
100

GaN reactive sputtering – N rich deposition / 800˚C /Si(111) substrate



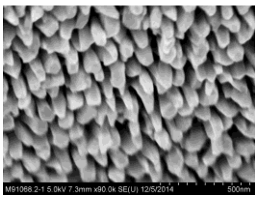
101

GaN reactive sputtering – N rich deposition / 650˚C /Si(111) substrate



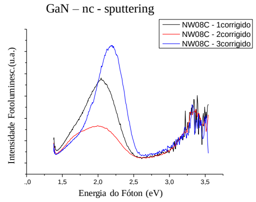
102

GaN reactive sputtering – N rich deposition / 650˚C /Si(111) substrate



103

GaN – nc - sputtering



[medida: F. Iikawa, Angela Unicamp]

104

Principais Resultados GaN

- Filmes compactos
  - => defeitos N-N / deformações
  - => melhora com trat. Térmico
- Nanocolunas
  - => conseguimos obter / controle
- Caminho para melhorar…

105

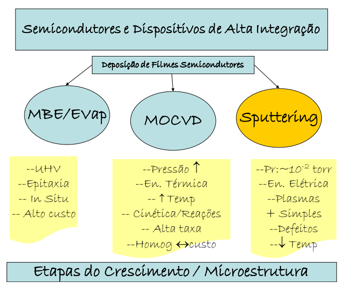
Outros resultados

- Nb_2O_5
  - células solares (muito bom resultado)
- Co_3O_4
  - melhoras do material (epitaxial sobre safira)
  - fotocatálise
  - a ser testado em células solares de perovskita

106

Conclusões

- Filmes usando plasmas ("frios") =>
  - papel importante das partículas com energias superiores às energias térmicas
- sputtering reativo
  - alternativa interessante p/ semicondutores
  - (muitos pontos a desenvolver /problemas a resolver)



rosquinha e café (de plasma!!)

Finalizando...

Física

- Conexão entre ciência e tecnologia
- físicos => papel importante (entendimento e desenvolvimento de novas tecnologias e novas aplicações)
- Vocês, seus estudos=> importantes para o desenvolvimento do país
- Busquem saber a fundo !! Sejam dedicados... inteligência vcs têm de sobra!!

O desafio é enorme.

=> seu talento
+ sua determinação
+ seu esforço

= país melhor!!

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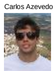

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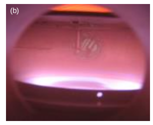

IV SEFiSMaT

Obrigado pela atenção!