



Epitaxia

*e*pi – sobre
*t*axis – de maneira ordenada

arranjar sobre

2

Epitaxia

Crescimento de uma camada de uma substância sobre um cristal de outra, de maneira que a estrutura da camada seja similar à do substrato.

A ordem cristalográfica do filme é significativamente influenciada pelo substrato.

3

Motivação

- Relembrando nossos circuitos de alta integração...

4

Seção transversal de dispositivo de memória RAM: CMOS

~ 1 micron

Laser semiconductor de heteroestrutura

Figure 1a: Sheffield Laser diagram
Courtesy: Sheffield University

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

Hetero-Estruturas LED - AlGaIn - InGaIn

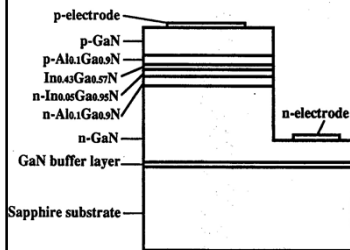


Fig. 20 The structure of green SQW LED.

... m u u u i i i itas camadas !

- + baixa densidade de defeitos entre camadas...
para não "espalhar" os elétrons

8

- Por que é importante crescer multiplas camadas / junções de diferentes materiais (heteroestruturas) ?

9

Idéias que se tornaram práticas...

- Prêmios Nobel
 - 1973
 - 2000
 - 2007

entre outras importantes...

10

Nobel 2000

Zhores Alferof



Herbert Kroemer



"for developing semiconductor heterostructures used in high-speed- and opto-electronics"

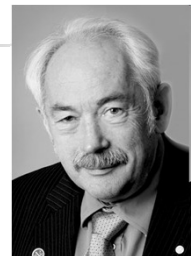
11

Nobel - 2007

Magneto-resistência gigante





Albert Fert



Peter Grünberg

Nobel - 1973

<http://nobelprize.org/mediaplayer/index.php?id=712&player=2>

[Entrevista Esaki Editada DVD.wmv](#)

Leo Esaki
 "for his experimental discoveries regarding tunneling phenomena in semiconductors"

13



Hetero-estruturas (super-redes)

Esquema de bandas de energia

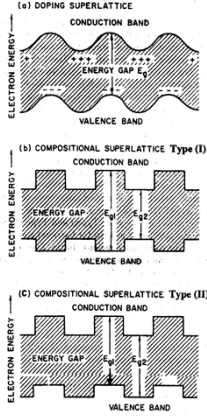
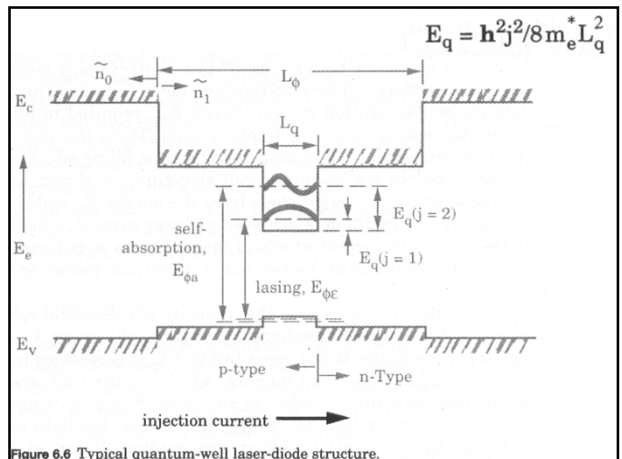
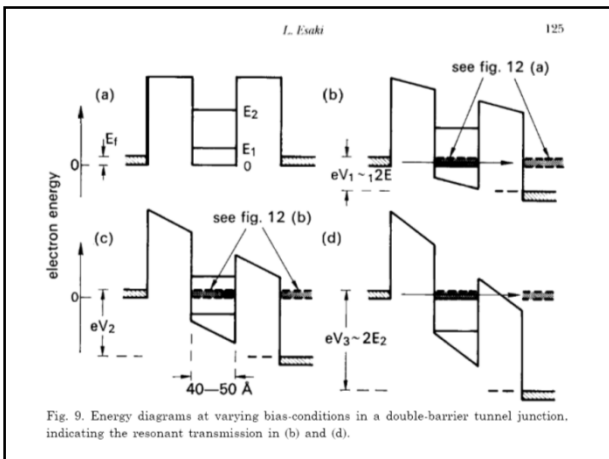
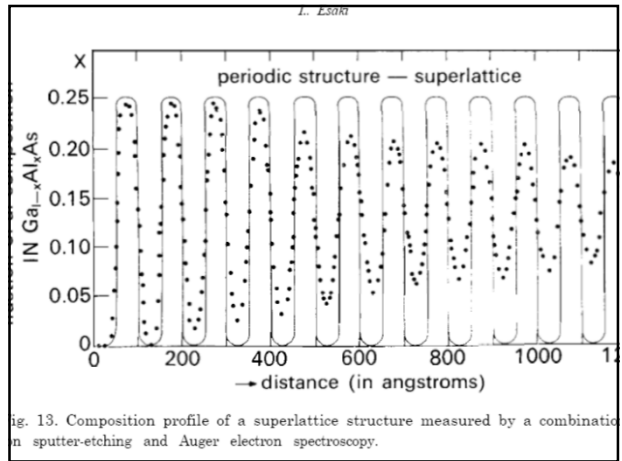


Figure 541-1: Spatial variations of the conduction and valence bandedge in (a) doping (p-i-p) superlattice (b) compositional superlattice (Type I) (c) compositional superlattices (Type II).



Relembrando Aplicações Hetero-Estruturas AlGaIn – InGaIn LEDs e LASERS

Fig. 20 The structure of green SQW LED.

Aplicações

<http://youtu.be/V9aV9ziELDw>

Uso em	Vídeos de alta definição Armazenamento de dados
Codificação	MPEG-2, MPEG-4 AVC (H.264), e VC-1
Capacidade	25 GB (camada simples) 50 GB (camada dupla)
Mecanismo de leitura	Laser 405 nm, 1x@36 Mbit/s 2x@72 Mbit/s 4x@144 Mbit/s 6x@216 Mbit/s ⁽¹⁾
Desenvolvido por	Sony, Blu-ray Disc Association
Dimensões	12 cm de diâmetro

Um Blu-ray regravável da Sony.

Epitaxia

ordem cristalográfica do filme

←

ordem cristalográfica do substrato.

- **Homoepitaxia** = filme e substrato de mesmo material.
Exemplos: Si/Si; GaAs/GaAs
- **Heteroepitaxia** = filme e substrato de material diferente.
Exemplos: GaN/Al₂O₃ (Safira)

Epitaxia

- Como crescer um cristal sobre outro?
 - Quais as condições ?
 - Para que ?

GaAs (001)/Fe(001)
FCC 0,565nm/BCC 0,573x0,5

Cu – FCC, $\sqrt{2}a_c = 0,512nm$

Cu [100]
Si [110]

Figure 6.1 Variations on heteroepitaxial symmetry: (a) $a_s \times 2$, (b) 45° rotation, and (c) CdTe[111] on GaAs(001). o = substrate surface atoms, * = first monolayer of epitaxy.

Hetero-Estruturas

25

Hetero-estruturas

Tensões e Defeitos

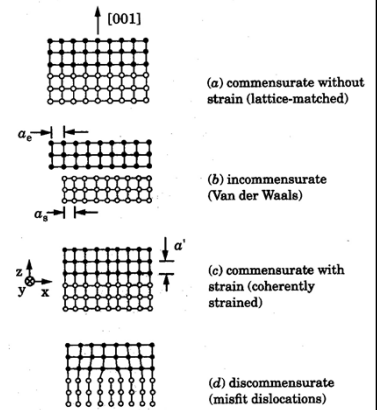


Figure 6.22 Modes of accommodating epilayer lattice (solid circles) to substrate lattice (white circles).

Fator de discordância de uma hetero-junção

$$f = \frac{(a_e - a_s)}{(a_e + a_s)/2} \approx (a_e - a_s)/a_s$$

Smith Eq.6.1

Epitaxia possível quando:

$$f \approx (a_e - a_s)/a_s < 0,15$$

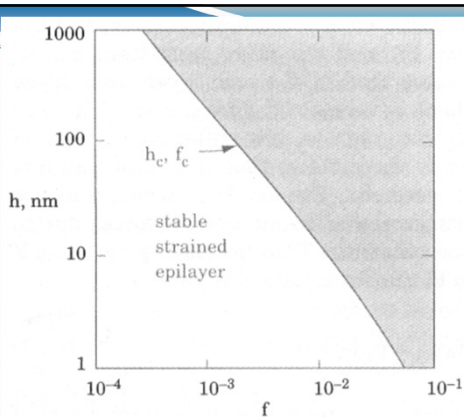
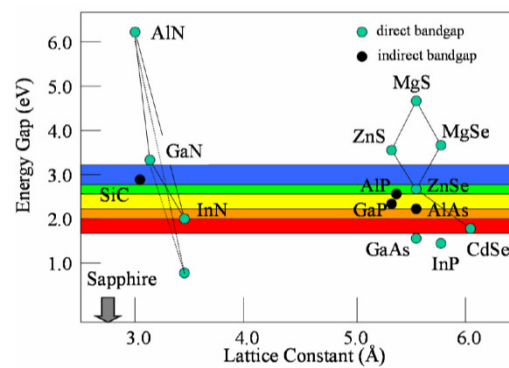
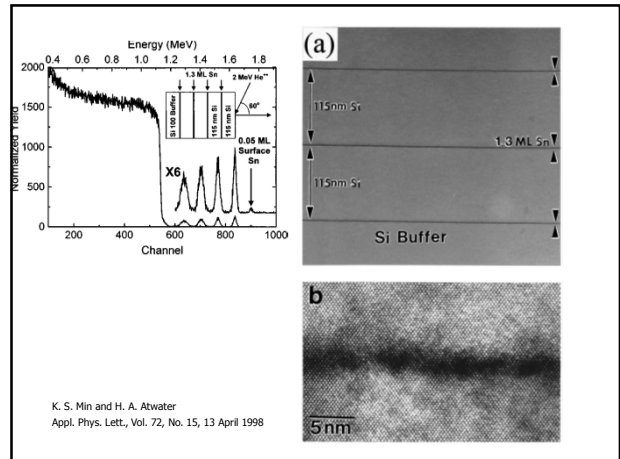
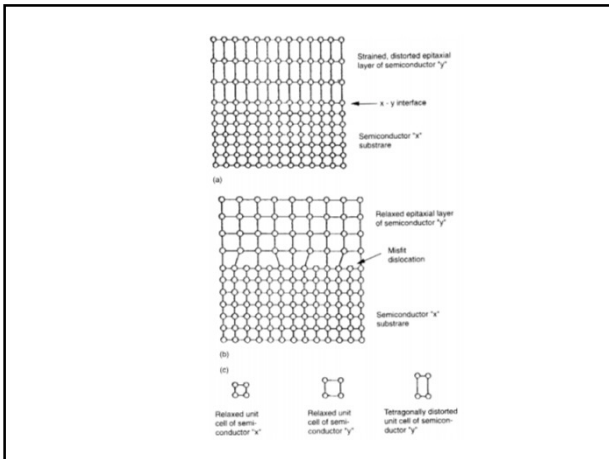


Figure 6.26 Relationship of critical thickness to lattice misfit for Si(001) epitaxy [Eq. (6.22)].

29

Parâmetro de Rede vs. Bandgap





Estudo de Caso

- GaN / Safira

33

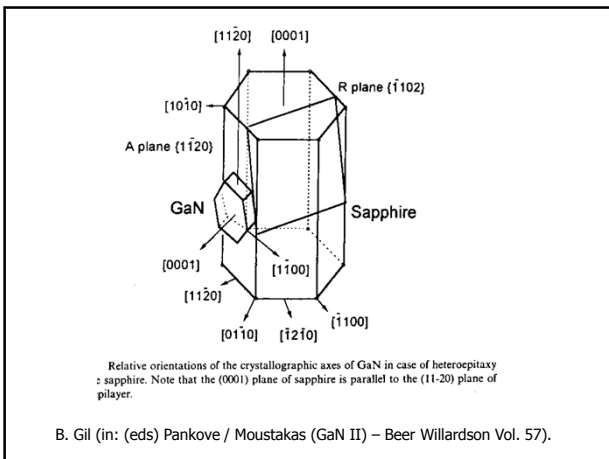
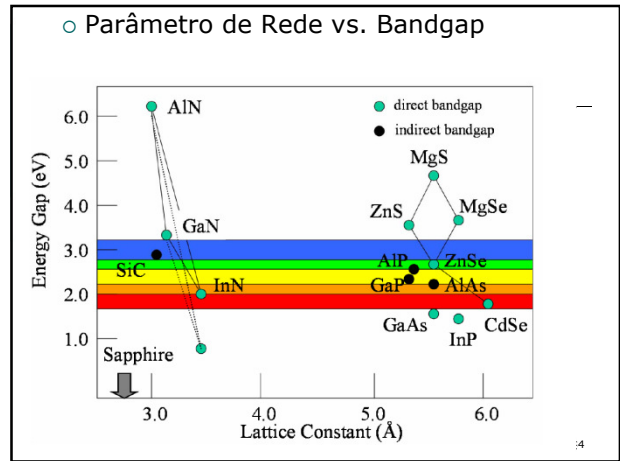
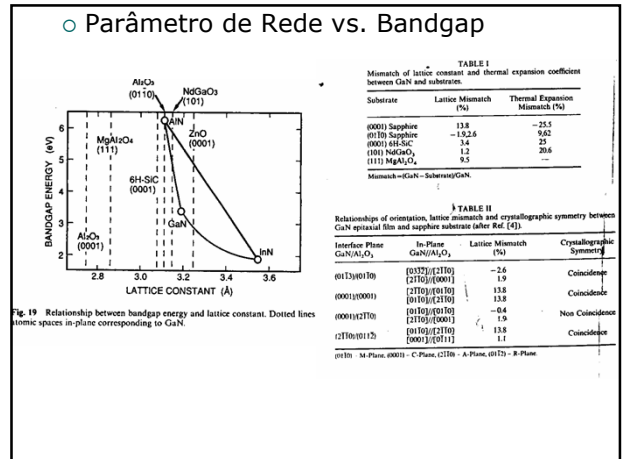
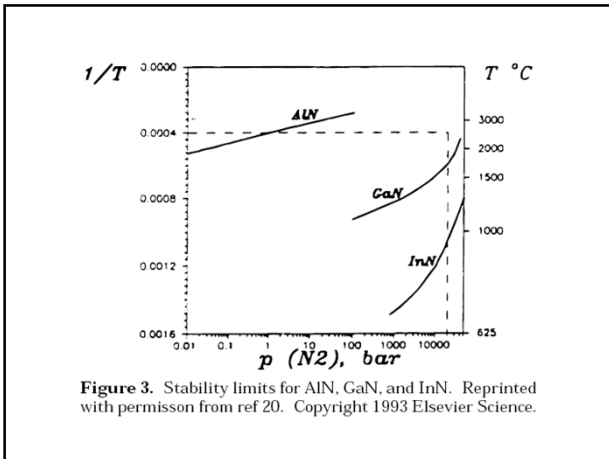


TABLE 2.1 Melting point T_m , specific heat C_p , and Debye temperature θ_D for some group-IV, III-V and II-VI semiconductors. C_p and θ_D are at 300 K

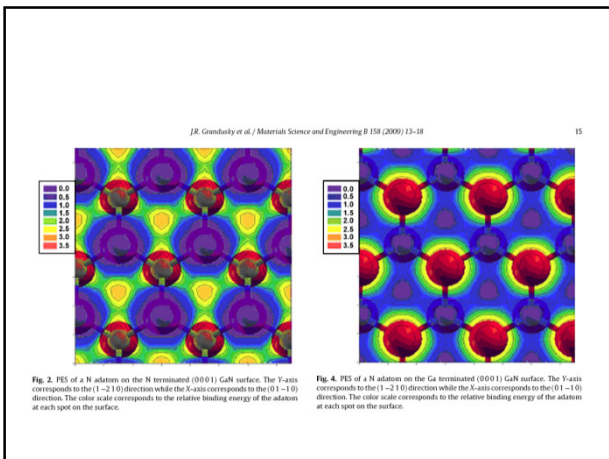
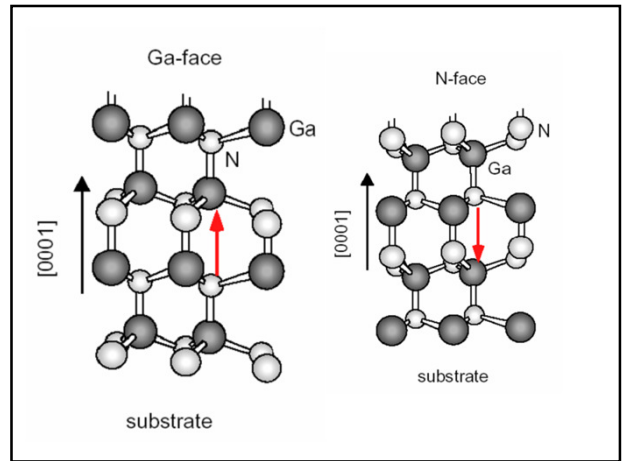
System	Material	T_m (K)	C_p (J/g K)	θ_D (K)
IV	Diamond	4100 ^a	0.5148	1870
	Si	1687	0.713	643
	Ge	1210.4	0.3295 ^b	348 ^b
	α -Sn		0.278 ^c	238 ^c
	3C-SiC	2810	0.677 ^d	1122
	6H-SiC	2810	0.58	1126
	15R-SiC	2810		
III-V	c-BN	>3246	0.643	1613
	h-BN		0.805	323
	BP	>3300	0.75	1025 ^e
	BAs	2300	0.408	800
	w-AlN	3487	0.728	988
	AlP	2823	0.727	687
	AlAs	1740	0.424	450
	AlSb	1338	0.326 ^b	370 ^b
	α -GaN	2791	0.42	821
	GaP	1730	0.313	493 ^f
GaAs	1513	0.327	370	
GaSb	991	0.344 ^b	240 ^b	



COMPOUND SEMICONDUCTOR
December 2009, Volume 18 Number 11
CONNECTING THE COMPOUND SEMICONDUCTOR COMMUNITY

GALLIUM NITRIDE
Which plane do you want to grow on?

FEATURED: Consolidation is on the cards in 2009 p13
POWER ELECTRONICS: Sticking up: GaN substrate...
HEALING BEAMS: Rays of hope: EU...
Ga-face
N-face
substrate



Conclusão

- Epitaxia
- Camadas de alta qualidade
- Junções / Hetero-estruturas
- Depende da concordância entre parâmetros de rede e bandgaps

43

Como faço para crescer camadas epitaxiais de alta qualidade ?

Resposta: MBE