



Impact of the (Al)GaInAs quantum wells composition on the structure and emission of InAs quantum dots embedded in AlGaAs/GaAs heterostructures



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Abstract

The main objective of this work is to investigate the impact of the composition of the confinement barriers on the light emission of InAs quantum dots embedded in AlGaAs/GaAs heterostructures, as well as on the structural parameters of the heterostructures in various states of growth, following thermal annealing and aging processes. The structures were labeled as #1 and #2, differing in the composition of their confinement barriers. Structure #1 consists of Al_{0.30}Ga_{0.70}As (capping layer) and In_{0.15}Ga_{0.85}As (buffer), while sample #2 have Al_{0.40}Ga_{0.45}In_{0.15}As (capping layer) and In_{0.25}Ga_{0.75}As (buffer), both containing InAs quantum dots. The samples were characterized using two different techniques: Photoluminescence (PL) and High-Resolution X-Ray Diffraction (HR-XRD), which provide information about their emission efficiency and structural parameters. PL studies indicated that after aging, there is an increase in the interdiffusion of Ga/In atoms, affecting the size and homogeneity of the quantum dots. Structure #2AV show the smallest quantum dot size due to the relaxation of elastic stresses, resulting in greater homogeneity in the quantum dot size due to the loss of peripheral quantum dots. HR-XRD studies and numerical adjustments indicate that a lower number of Pendellösung peaks may reflect lower quality in the samples, revealing phenomena of Ga/In interdiffusion, as well as the presence of elastic stress relaxation mechanisms in the structure. The aging time of the samples significantly impacts their compositions and emissions, affecting the homogeneity and quality of the quantum dots.

Materials and Methods

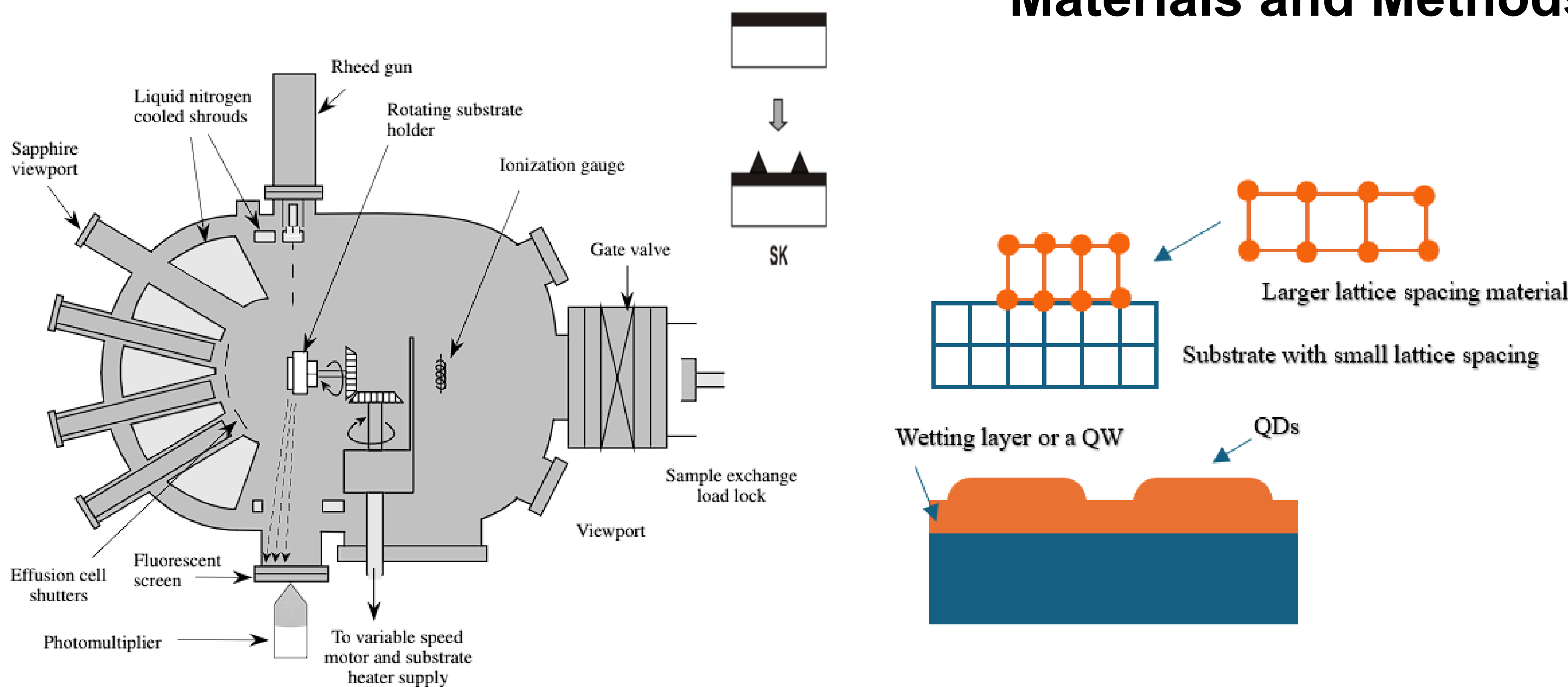


Fig. 1. Schematic of the MBE growth system.

Fig. 2. Stranski-Krastanov (S-K) growth mode.

Two Quantum Well (QW) compositions were analyzed, both with InAs QDs on GaAs substrates:

- Structure #1: Capping Layer: Al_{0.30}Ga_{0.70}As; Buffer Layer: In_{0.15}Ga_{0.85}As.
- Structure #2: Capping Layer: Al_{0.40}Ga_{0.45}In_{0.15}As; Buffer Layer: In_{0.25}Ga_{0.75}As

Table 1. Identification nomenclature for each sample.

As-Prepared Samples	Aged Samples	Capping Layer	Thermal Annealing
#1A	#1AV	Al _{0.30} Ga _{0.70} As	Sin TT
#1B	#1BV	Al _{0.30} Ga _{0.70} As	640 °C
#1C	#1CV	Al _{0.30} Ga _{0.70} As	710 °C
#2A	#2AV	Al _{0.40} Ga _{0.45} In _{0.15} As	Sin TT
#2B	#2BV	Al _{0.40} Ga _{0.45} In _{0.15} As	640 °C
#2C	#2CV	Al _{0.40} Ga _{0.45} In _{0.15} As	710 °C

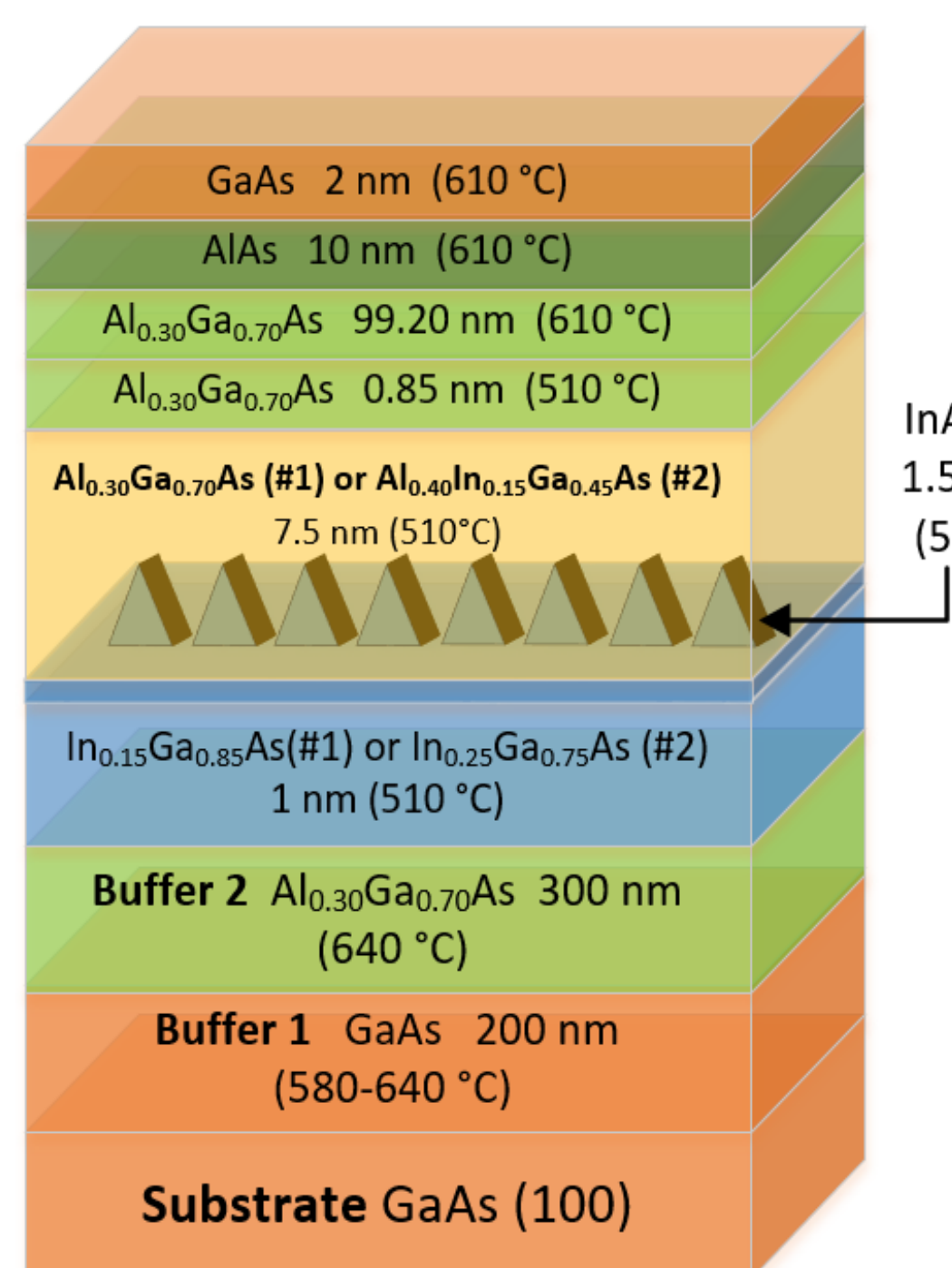


Fig. 3 The design of QD structure #1 and #2.

Photoluminescence (PL): Used to measure light emission efficiency and QD composition across a temperature range of 10 K to 450 K.

High-Resolution X-Ray Diffraction (HR-XRD): Employed to investigate structural parameters such as layer thickness, composition, and lattice strain/relaxation

Experimental results

PL Study - Aging Effects

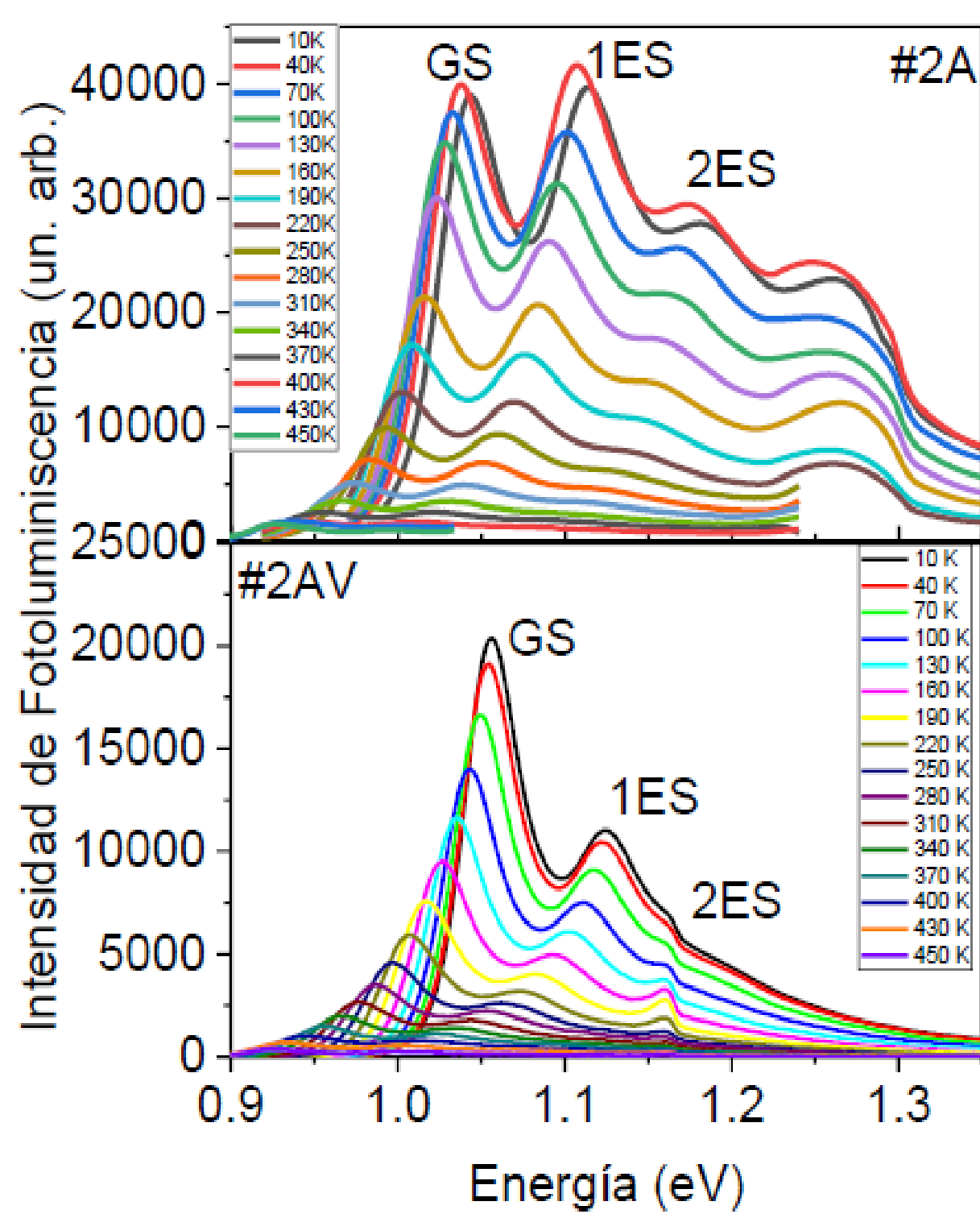


Fig. 4 Comparison of PL spectra measured at temperatures from 10 K to 450 K.

Table 2. Comparison of results from the FL analysis of structures #1 & #2

Muestra	Barrera de confinamiento	GS (eV)	1ES (eV)	ΔE(GS-1ES) (meV)	I _{GS} /I _{1ES}	FWHM (meV)
#1A	Al _{0.30} Ga _{0.70} As	1.118	1.181	63	0.909	56
#1AV	Al _{0.30} Ga _{0.70} As	1.124	1.179	55	1.68	52
#1B	Al _{0.30} Ga _{0.70} As	1.126	1.186	60	0.76	58
#1BV	Al _{0.30} Ga _{0.70} As	1.132	1.190	58	0.753	49
#1C	Al _{0.30} Ga _{0.70} As	-	1.225	-	1.608	104
#1CV	Al _{0.30} Ga _{0.70} As	-	1.286	-	3.61	95
#2A	Al _{0.40} Ga _{0.45} In _{0.15} As	1.043	1.115	72	1	53
#2AV	Al _{0.40} Ga _{0.45} In _{0.15} As	1.056	1.123	67	1.25	40
#2B	Al _{0.40} Ga _{0.45} In _{0.15} As	1.051	1.116	65	0.920	62
#2BV	Al _{0.40} Ga _{0.45} In _{0.15} As	1.058	1.123	65	0.433	38
#2C	Al _{0.40} Ga _{0.45} In _{0.15} As	1.056	1.118	62	0.750	70
#2CV	Al _{0.40} Ga _{0.45} In _{0.15} As	1.135	1.189	54	0.768	59

Structural Analysis

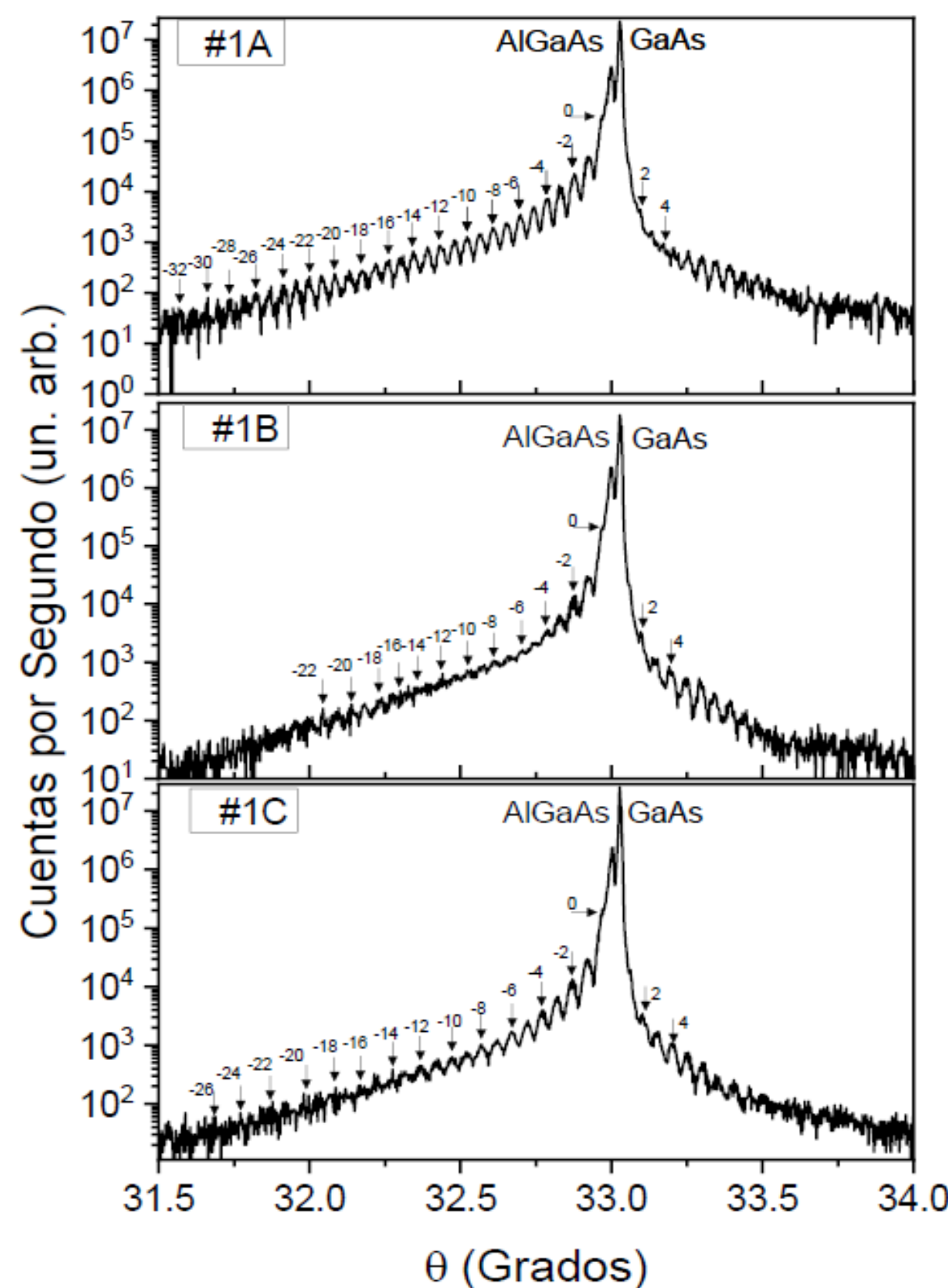


Fig 5. HR-XRD scans for sample #1

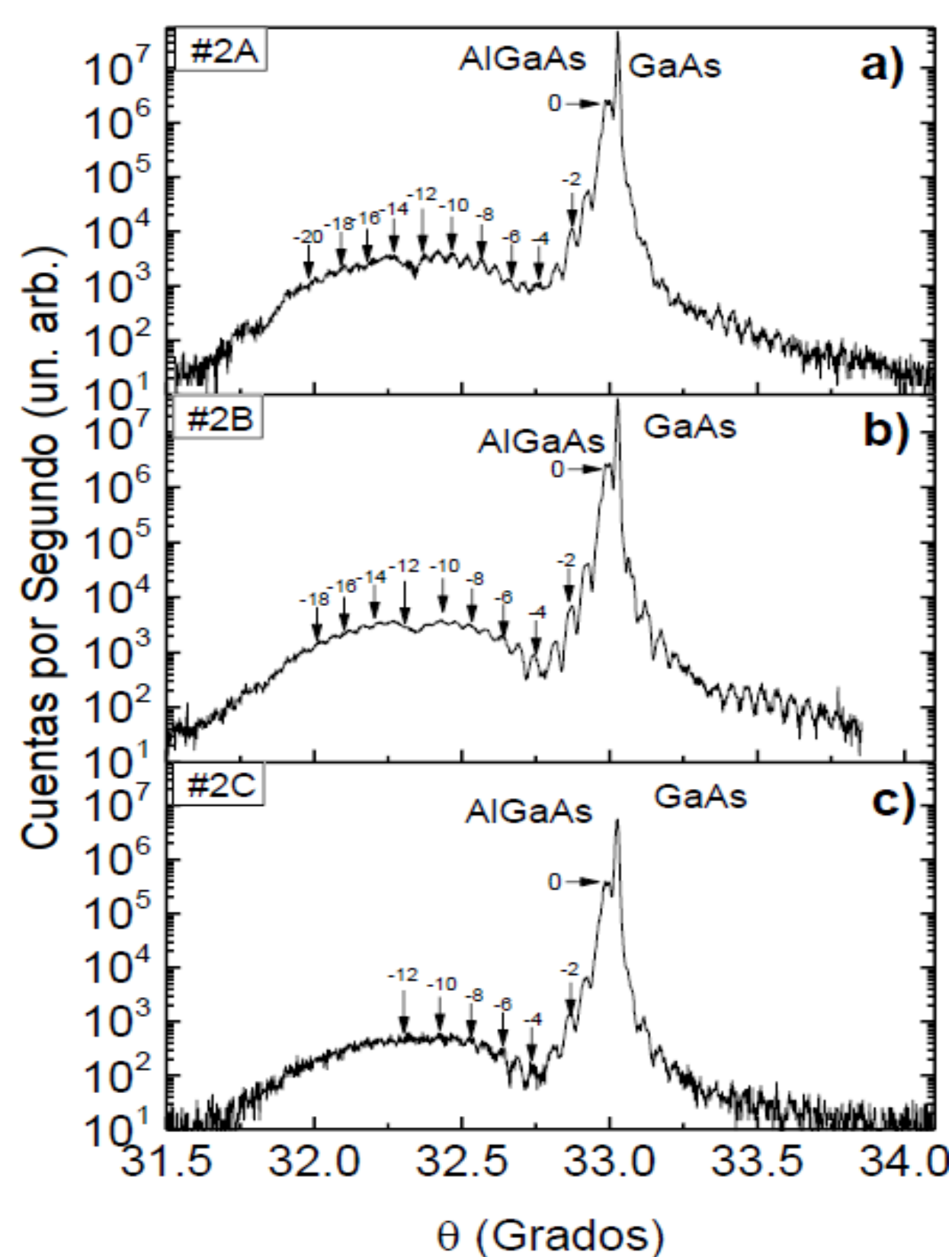


Fig 6. HR-XRD scans for sample #2

Numerical Fitting

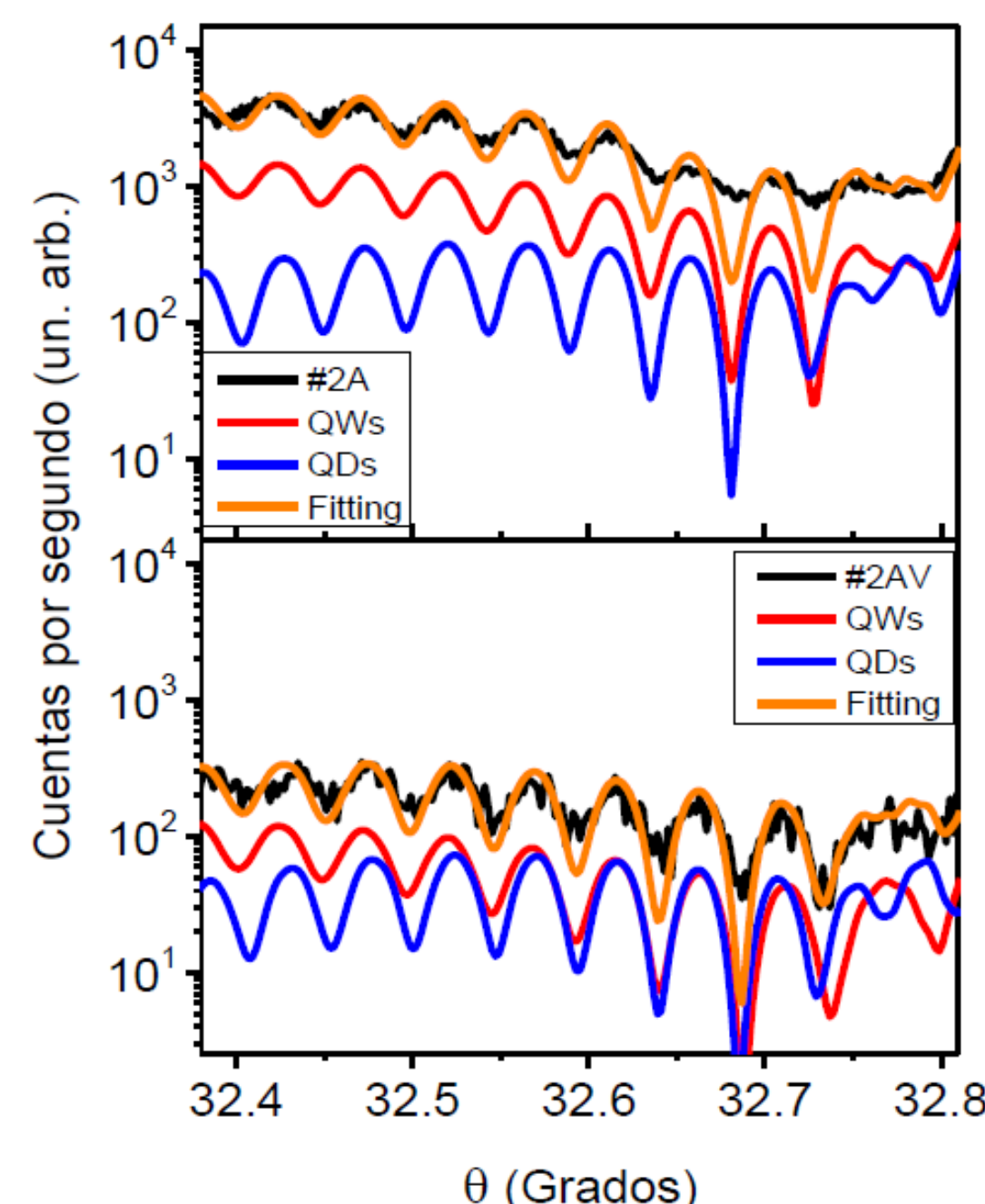


Fig 7. Numerical Fitting for the Samples #2A & #2AV

Table 3. Values Obtained from the Numerical Fitting

Muestra #2A-Valores Originales			Ajuste para área entre PCs			Ajuste incluyendo PCs		
Nº	Composicion Tecnológica	Tamaño nm	Composición	Tamaño nm	Composición	Tamaño nm		
L10	GaAs	2	GaAs	2	GaAs	2		
L9	AlAs	10	AlAs	10	AlAs	10		
L8	Al _{0.30} Ga _{0.70} As	93	Al _{0.30} Ga _{0.70} As	93	Al _{0.30} Ga _{0.70} As	93		
L7	Al _{0.30} Ga _{0.70} As	0.80	Al _{0.30} Ga _{0.70} As	0.64	Al _{0.30} Ga _{0.70} As	-		
L6	Al _{0.40} Ga _{0.45} In _{0.15} As	7.50	Al _{0.40} Ga _{0.45} In _{0.15} As	7.50	Al _{0.40} Ga _{0.45} In _{0.15} As	0.44		
L5	InAs PCs	1.575ML	-	-	InAs PCs	7.7		
L4	InAs WL	0.40	In _{0.30} Ga _{0.30} As	0.36	In _{0.30} Ga _{0.30} As	0.36		
L3	In _{0.25} Ga _{0.75} As	1.00	In _{0.25} Ga _{0.75} As	1.20	In _{0.25} Ga _{0.75} As	1.2		
L2	Al _{0.30} Ga _{0.70} As	300	Al _{0.30} Ga _{0.70} As	300	Al _{0.30} Ga _{0.70} As	300		
L1	GaAs	200	GaAs	200	GaAs	200		
	Periodo P	114.7		114.7		114.7		

Muestra #2AV-Valores Originales			Ajuste para área entre PCs			Ajuste incluyendo PCs		
Nº	Composicion	Tamaño nm	Composicion	Tamaño nm	Composicion	Tamaño nm		
L10	GaAs	2	GaAs	2	GaAs	2		
L9	AlAs	10	AlAs	10	AlAs	10		
L8	Al _{0.30} Ga _{0.70} As	93	Al _{0.30} Ga _{0.70} As	93	Al _{0.30} Ga _{0.70} As	93		
L7	Al _{0.30} Ga _{0.70} As	0.80	Al _{0.30} Ga _{0.70} As	0.64	Al _{0.30} Ga _{0.70} As	-		
L6	Al _{0.40} In _{0.15} Ga _{0.45} As	7.5	Al _{0.40} In _{0.15} Ga _{0.45} As	7.5	Al _{0.40} In _{0.15} Ga _{0.45} As	0.61		
L5	InAs PCs	1.575ML	InAs PCs	-	InAs PCs	7.53		
L4	InAs WL	0.40	In _{0.30} Ga _{0.30} As	0.36	In _{0.30} Ga _{0.30} As	0.36		
L3	In _{0.25} Ga _{0.75} As	1	In _{0.25} Ga _{0.75} As	1.2	In _{0.25} Ga _{0.75} As	1.2		
L2	Al _{0.30} Ga _{0.70} As	300	Al _{0.30} Ga _{0.70} As	300	Al _{0.30} Ga _{0.70} As	300		
L1	GaAs	200	GaAs	200	GaAs	200		
	Periodo P	114.7		114.7		114.7		