



HAL
open science

Automated growth of AlAs/GaAs Bragg mirror with real-time feedback reflectometry.

Pierre Gadras, Léo Bourdon, Karim Ben Saddik, Guilhem Almuneau, Alexandre Arnoult

► **To cite this version:**

Pierre Gadras, Léo Bourdon, Karim Ben Saddik, Guilhem Almuneau, Alexandre Arnoult. Automated growth of AlAs/GaAs Bragg mirror with real-time feedback reflectometry.. EUROMBE 2025, Mar 2025, Auron, France. 2025. ⟨hal-04994996⟩

HAL Id: hal-04994996

<https://cnrs.hal.science/hal-04994996v1>

Submitted on 19 Mar 2025

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

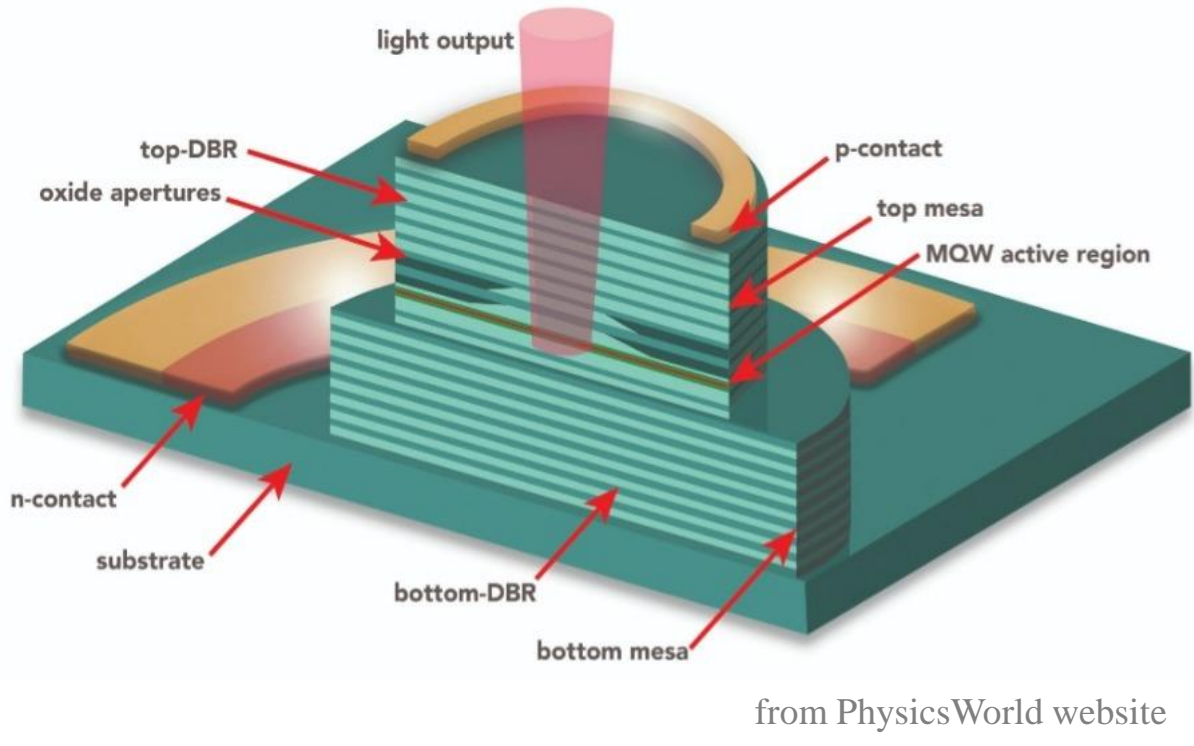
L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.



Distributed under a Creative Commons CC BY-NC-ND 4.0 - Attribution - Non-commercial use - No Derivative Works - International License

Motivations

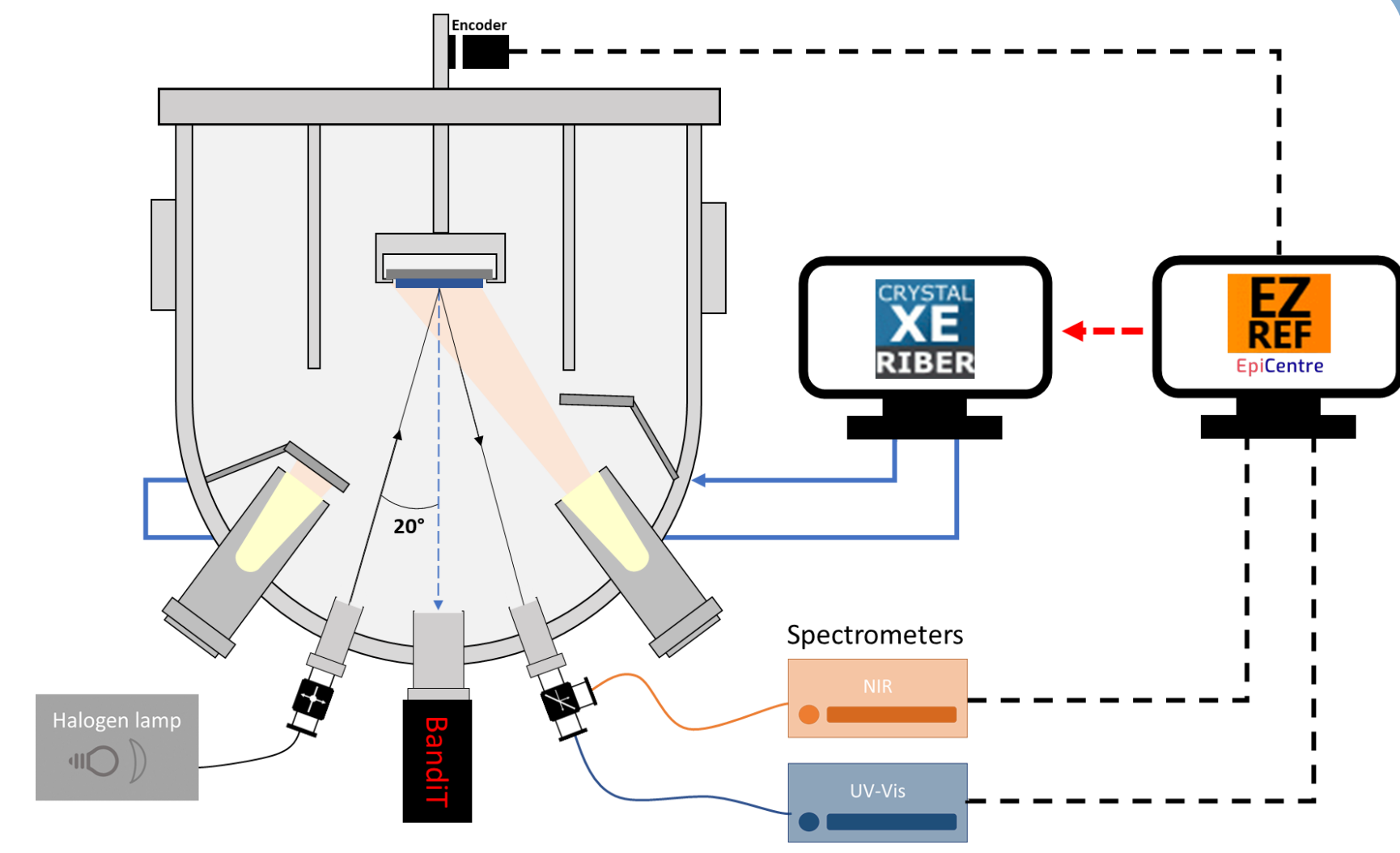
High performances VCSELs are complex component posing a challenge for epitaxial grower. They require extensive calibrations and are sensitive to deviations. Improved control over the epitaxy process through direct measurement could be a game-changer. However, no universal practical tool has been implemented to date. With EpiCentre, joint lab with RIBER, we're working on combining *in-situ* measurements in molecular beam epitaxy (MBE) to achieve advanced materials growth in real time.



from PhysicsWorld website

In this work, we demonstrate the **automated controlled growth of a GaAs/AlAs Distributed Bragg Reflector (DBR) centered at 940 nm** without prior precise cell flow calibrations.

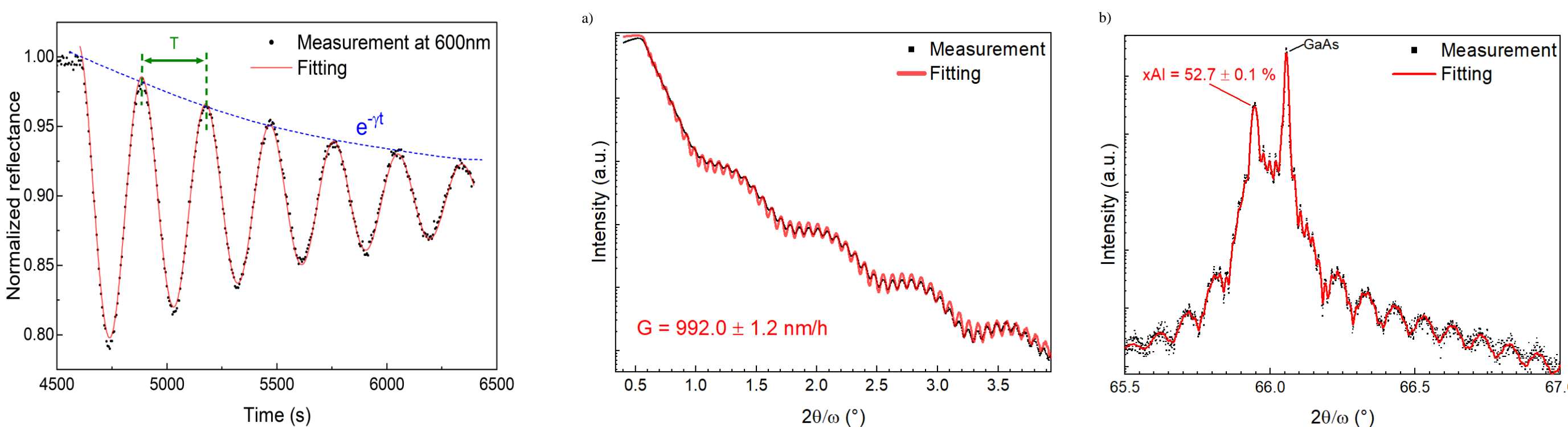
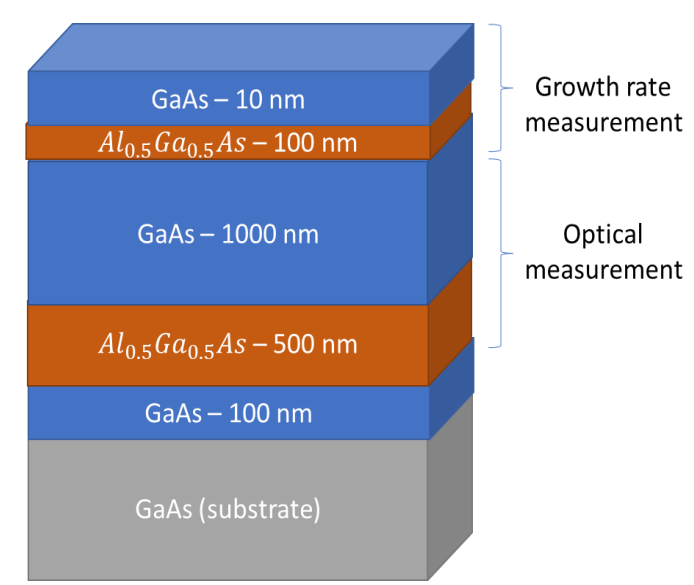
- Under MBE growth conditions, we measured the refractive indices (n , k) of the $Al_xGa_{1-x}As$ alloys using in-situ reflectometry.
- Based on these preliminary calibrations, we grew a DBR sample using a feedback-controlled process from in-situ spectral reflectance measurements.



Optical indices measurement

To measure optical indices, we grow a layer of given composition and measure in-situ in real time the spectral reflectance.

In the same time, we set the growth temperature to 600°C through band-edge thermometry (BandiT)



In-situ reflectivity measurement of $Al_{0.53}Ga_{0.47}As$ thin film at 600nm and 600°C. Fitted damped cosine function (red solid line) allows the extraction of T and γ at the given wavelength (blue dashed line).

X-ray measurement a) in reflection and b) at (004) diffraction angle for $Al_{0.53}Ga_{0.47}As$ sample

$$n = \frac{\lambda}{2 * G * T * \cos\theta_1}$$

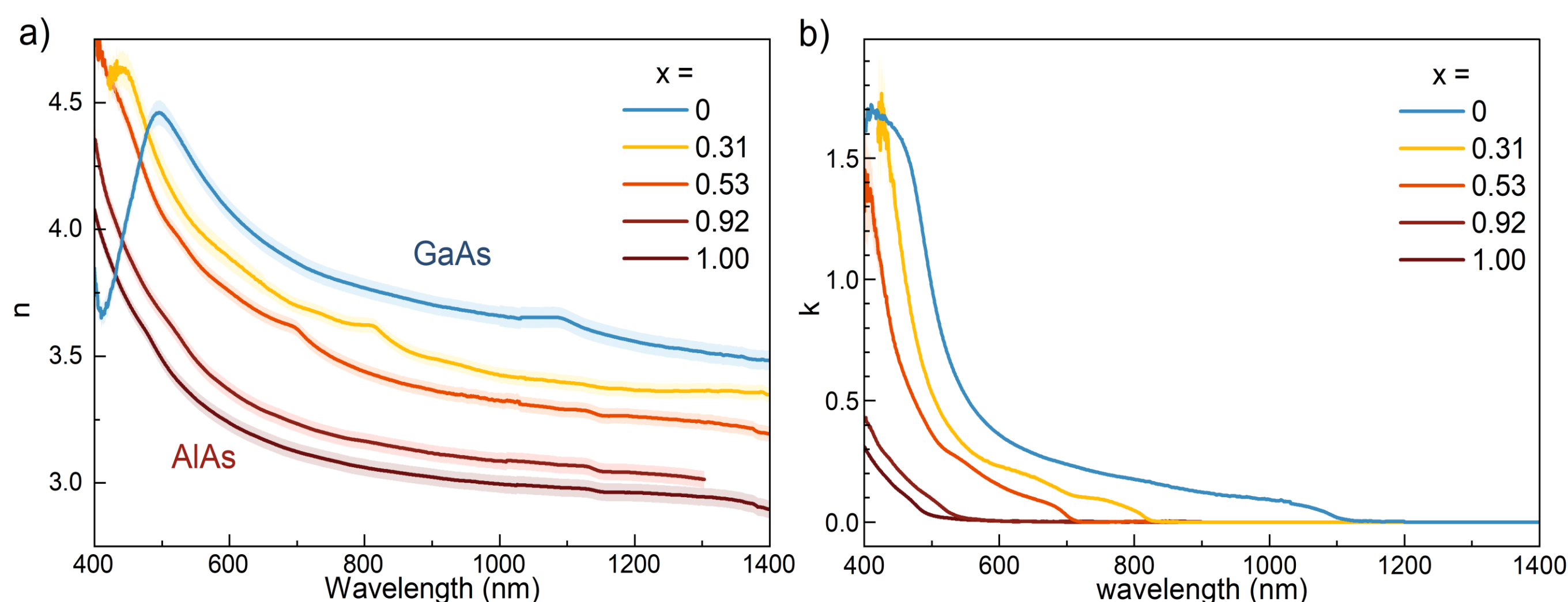
$$k = \frac{\lambda * \gamma}{4\pi * G * \cos\theta_1}$$

With :

- T : Reflectance oscillation period
- γ : damping coefficient
- λ : wavelength
- G : growth rate
- θ_1 : propagating angle within the film

Detailed calculation in [1]

Combining in-situ reflectance with ex-situ X-ray Reflectometry measurement, we deduce **optical indices dispersion of $Al_xGa_{1-x}As$ at growth temperature** :

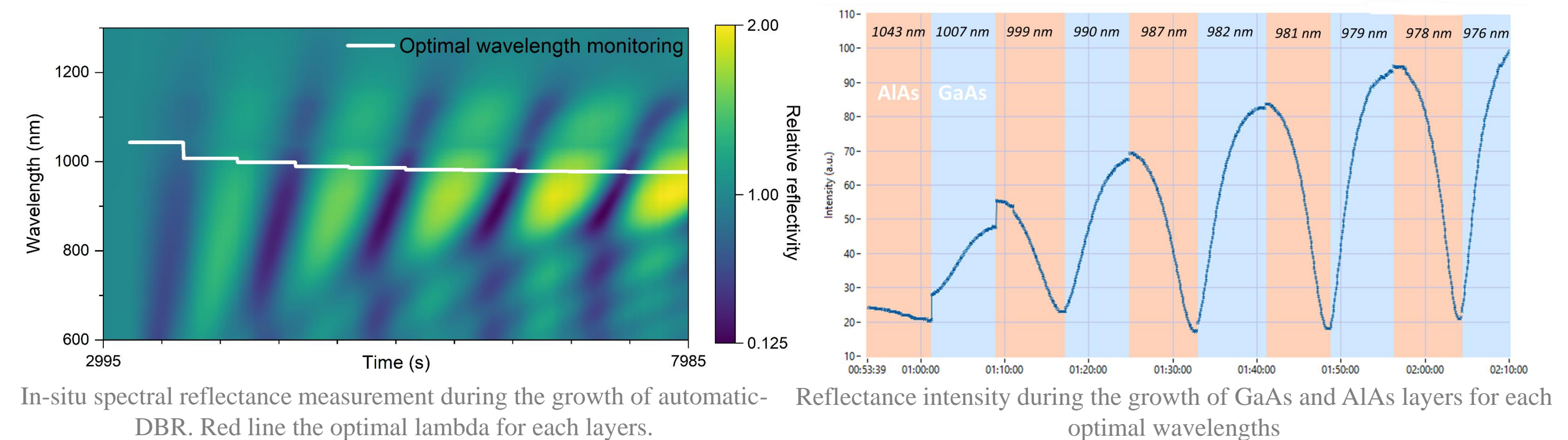


In-situ measured a) refractive indices and b) extinction coefficients of $Al_xGa_{1-x}As$ at 600°C. Shaded colors correspond to the estimated vertical errors.

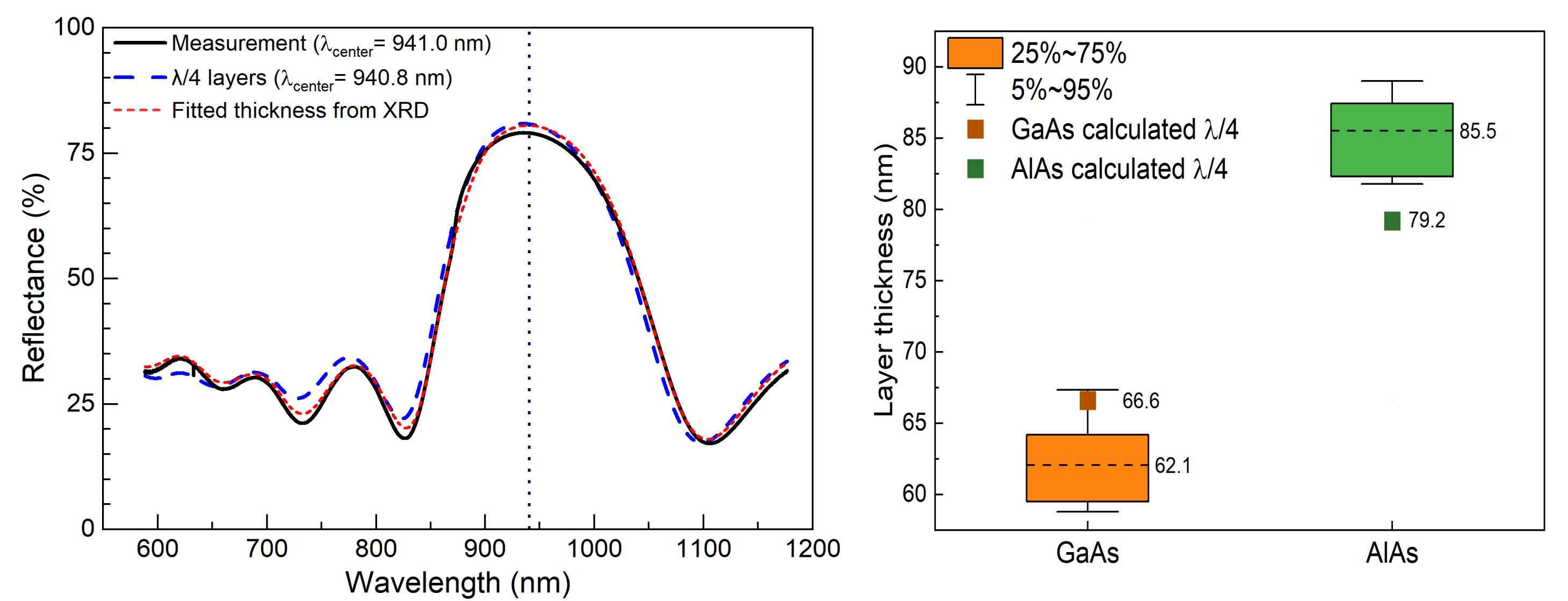
Optical growth control

Growth Strategy:

- Simulate the in-situ reflectance of a perfect $5 \times$ GaAs/AlAs DBR using the measured optical indices and the scattering matrix method.
- Identify wavelengths where reflectance reaches an extremum at the end of each perfect quarter-wavelength layer.
- Use these **optimal wavelengths** [2] during growth to trigger shutters in real time upon detecting a reflectance extremum.



In-situ spectral reflectance measurement during the growth of automatic-DBR. Red line the optimal lambda for each layers. Reflectance intensity during the growth of GaAs and AlAs layers for each optimal wavelengths



FTIR measurement of automatic-DBR growth compared to expected by SMM simulation. Statistical distribution of layer thicknesses from XRD measurement of the GaAs/AlAs DBR compared to the calculated $\lambda/4$ thickness.

Very good agreement to the center wavelength of the DBR
Layers thicknesses differ from calculated value and are variable. } Self-phase compensation effect [3]

- Challenge to accurately identifying extrema in the reflectance signal during growth
- Need to do more sample with more periods and configurations (FP cavity)

Conclusion & Perspectives

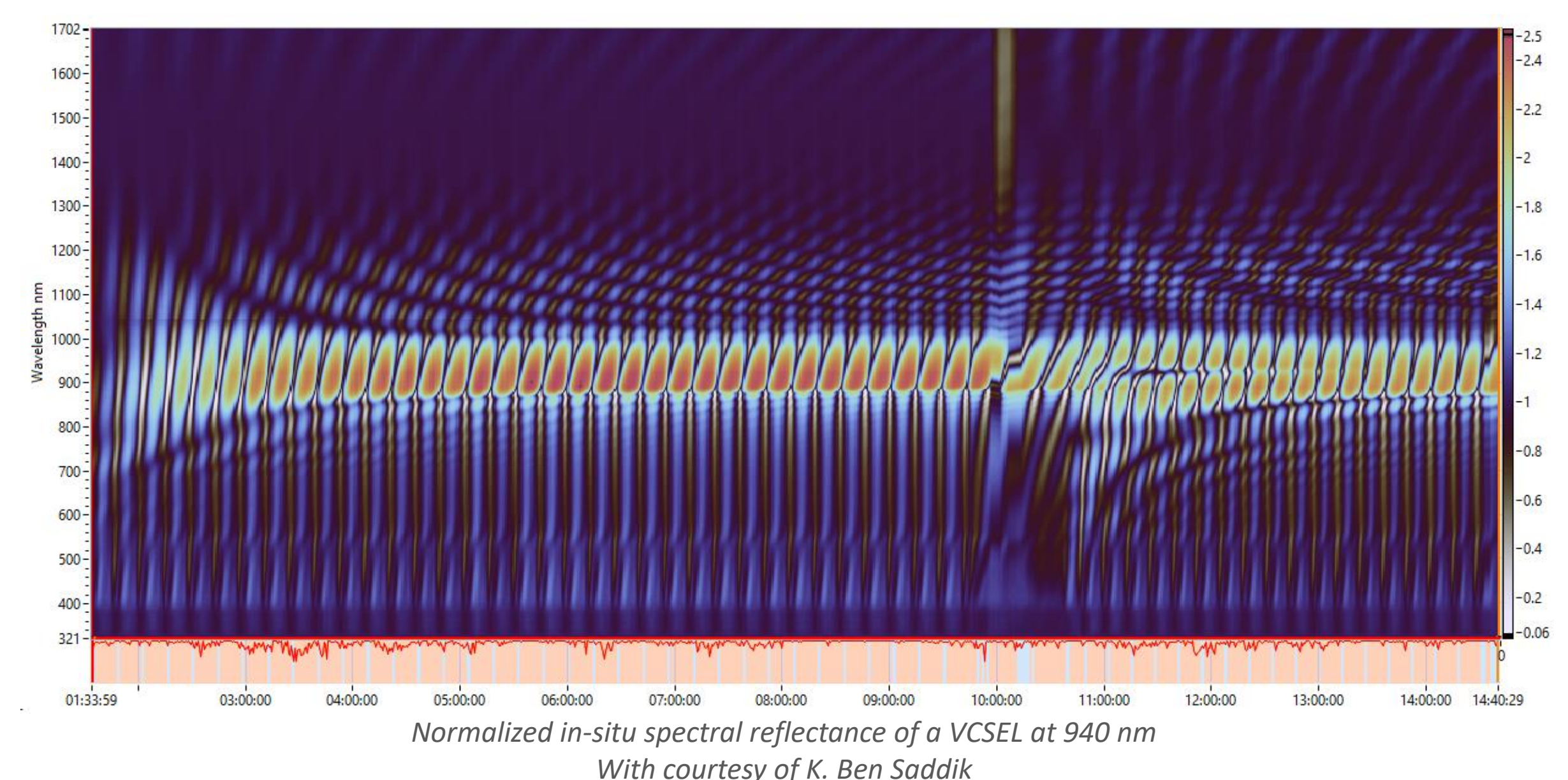
Key Contributions:

- Established methodology to measure **refractive index (n , k)** of AlGaAs at growth temperature → Complements limited literature data.
- Used measured refractive indices to **model in-situ reflectance** during DBR growth.
- Implemented **optimal wavelength method** for real-time DBR growth control.
- Feedback control** of the MBE system.
- Achieved **targeted DBR center wavelength with high reflectivity**, but with non-ideal quarter-wavelength layers.

Perspectives:

- Optical flux measurement** [4] → Enables alloy concentration control.
- Extending this method to **grow more complex structures**.

➔ **Toward fully controlled VCSEL growth**



Normalized in-situ spectral reflectance of a VCSEL at 940 nm
With courtesy of K. Ben Saddik

References:

- W. G. Breiland and K. P. Killeen, JAP, 1995, (doi: 10.1063/1.360496)
- V. Bardinal, R. Legros, and C. Fontaine, APL, 1995, (doi: 10.1063/1.114903)
- M. Vignaux, F. Lemarchand, C. Grezes-Beset, and J. Lumeau, Opt. Express, 2017, (doi: 10.1364/OE.25.018040)
- S. A. Chalmers and K. P. Killeen, APL, 1993, (doi: 10.1063/1.110788)

Acknowledgments:

RENATECH (French Network of Technology Platforms) at LAAS-CNRS
Epicentre, RIBER LAAS-CNRS joint lab

Laboratoire conventionné avec

