In-situ metrology for robust endpoint detection in InP dry etching processes

This application note presents an innovative three-wavelength in-situ metrology technique for endpoint detection EPD [1] in plasma etch processes used in the manufacture of InP-based lasers. This novel EPD solution provides nanometer-level accuracy and robust run-to-run consistency, even with significant variations in etch rate. It uses three wavelengths from a range between 340 and 670 nm to provide deep etch control, a capability not achievable with single wavelength EPD systems. By simultaneously monitoring etch depth and thin film interfaces, the new system meets the stringent requirements for run-to-run consistency.

In the manufacturing of InP lasers, a critical challenge is the precise control of etching in complex heterostructures, where dimensions range from a few nanometers to several micrometers, and the need for smooth surfaces and facets is paramount. Accurate control of key parameters, such as total etch depth, the distance from a thin film interface, and the remaining thickness, is essential. Reflectance-based in-situ monitoring is ideally suited for this purpose. However, commercially available solutions typically rely on a single reflectance wavelength, which limits depth resolution. Traditional systems usually operate at wavelengths of 670 nm (or sometimes 633 nm) or 950 nm, where Fabry-Pérot oscillations (FPO) can be observed up to a thickness of approximately 700 nm. Such long wavelengths are inadequate for detecting thin layers or interfaces, such as those in ternary/binary or quaternary/binary InP-based alloys.

LayTec's TRIton® endpoint detection system overcomes this limitation by employing a combination of three optimized wavelengths, significantly improving accuracy in controlling key etch depth metrics.

In this application note, we refer to results from Dr. Jean Decobert et al. at III-V Lab in Palaiseau, France [2], demonstrating the benefits of this EPD system for dry-etching of InP laser structures. LayTec's TRIton® in-situ plasma etch monitoring enables robust ±1nm precision in etch depth control for single-mode InP-based ridge waveguide lasers, which are crucial for high-speed transmitters in optical fiber communication networks.

The in-situ metrology tool was integrated into an Oxford PlasmaLab 100 ICP-RIE 180 at III-V Lab, with direct communication between TRIton® and the etcher (Fig. 1 upper image). Trigger signals are sent from the EtchNet software to the etcher, allowing plasma processes to be terminated when the targeted etch depth is reached, as determined by the EPD algorithm. TRIton® measures the etch transient, i.e., reflectance-based intensity changes over time as the InP laser structure is etched down to the lower cladding layer of the InP substrate **(Fig. 2)**.

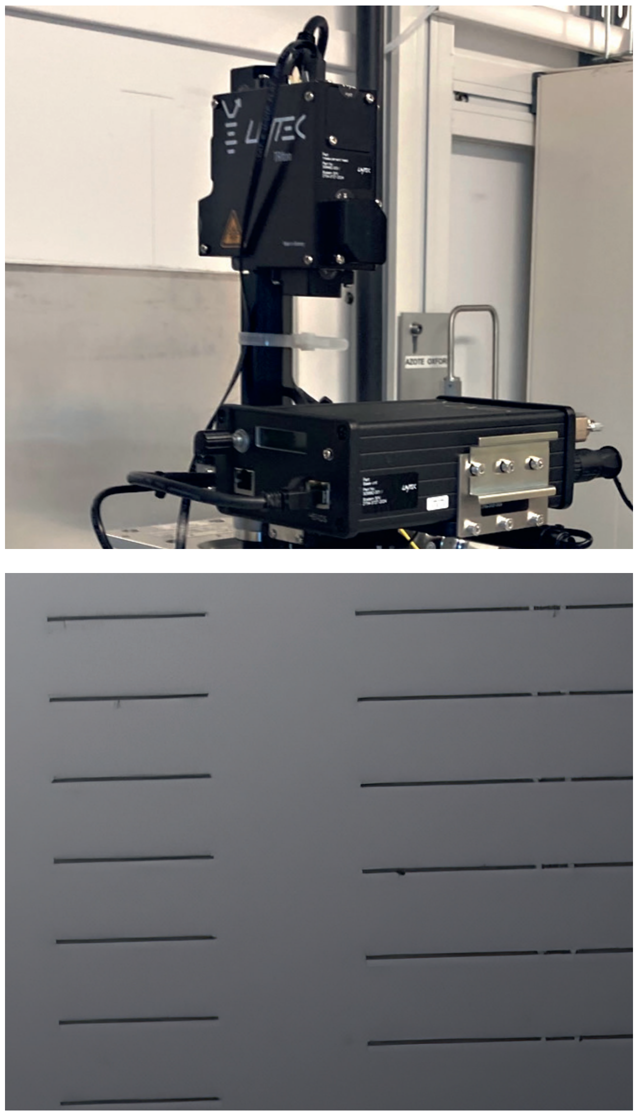

Fig. 1 A TRIton® system installed on an Oxford Instrument Plasma Technology chamber (upper image), and the camera captured an image (bottom) of an InP wafer's top surface, highlighting a test structure based on ~ 10 µm horizontal narrow strips spaced by ~ 400 µm.

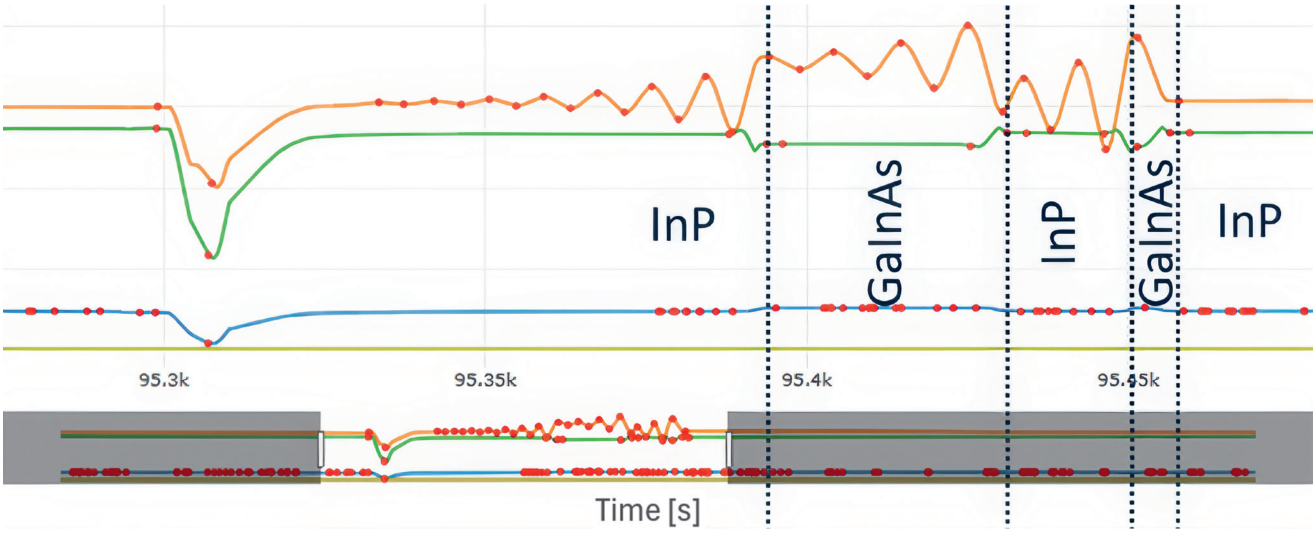

Fig. 2 Snapshot of an etch transient recorded with TRIton® during plasma etch monitoring. The orange curve represents reflectance at 670 nm, which shows FPO in quaternary and InP layers thinner than ~700 nm, enabling real-time etch rate extraction. The green curve depicts the reflectance etch transient at 405 nm, showing a step-like change that facilitates real-time detection of binary/quaternary interfaces. The red dots mark the peak positions detected by EtchNet, which are used for “counting” the interference oscillation for assessing the etching progress. The blue curve corresponds to 340 nm etch transient.

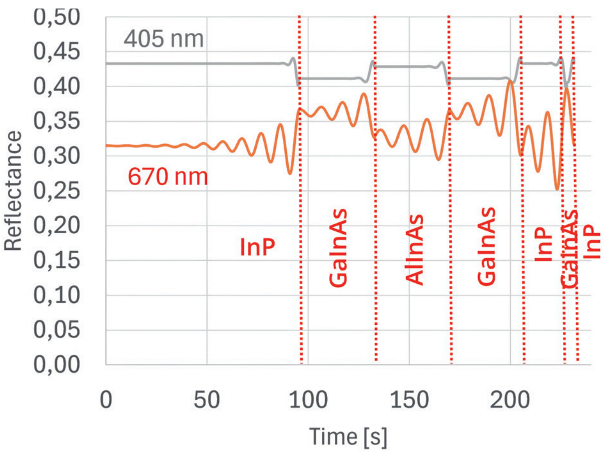

Fig. 3a) Simulated etch transient of a GaInAs/InP structure at 405 and 670 nm.

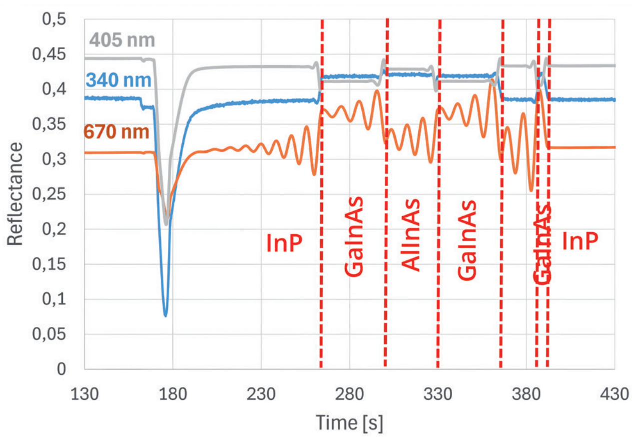

Fig. 3b) Etch transient measured with TRIton® at 3 wavelengths during etch through run of the same modeled structure.

Real-time tracking of etch progress

The innovation of the TRIton® system is the use of three different wavelengths that reveal specific features in the reflectance trace ('etch transient'), allowing much more accurate monitoring of etch depth and interface detection. Furthermore, the three measurement wavelengths can be selected between 340 nm and 950 nm. This way the system can be customized to suit different material systems.

In this study, wavelengths of 340 nm, 405 nm and 670 nm were selected to meet the requirements of a GaInAsP/InP double heterostructure laser grown by MOCVD. The system achieves high accuracy by combining interface detection at shorter wavelengths with FPO-based etch depth control at longer wavelengths. The increase in FPO amplitude as the InP film is etched away can be seen in both the simulated etch transient **(Fig. 3a)** and the measured transient **(Fig. 3b)** at 670 nm. As can be seen, the simulations **(Fig. 3a)** and the experimental data **(Fig. 3b)** are in very good agreement. Wavelengths lower than the bandgap (e.g. 405 nm and 340 nm) show high absorption, resulting in a strong damping of the FPO and reflection contrast near an interface, allowing e.g. the detection of a barrier/quantum well interface. This feature - an abrupt change in the slope of the reflectance - is clearly visible at the binary/ternary interface (InP/InGaAs) in **Fig. 3a**, as well as in the TRIton® data **Fig. 3b** (grey line for 405 nm and blue line for 340 nm).

Measuring quantum wells

In a second example, a quantum well structure is analyzed. In more detail it is a double heterostructure laser grown on an InP wafer with a thick p-type Zn-doped InP/GaInAs upper cladding, a central active zone based on strain-compensated AlGaInAs multiple quantum wells (MQWs) emitting at 1.55 µm, and a Si-doped InP lower n-type cladding. An etch-through run was performed to analyze the structure and define the steps for an EPD algorithm.

Figure 4a shows the etch transients recorded when etching through the entire structure. The longest wavelength, 670 nm, clearly exhibit FPOs for InP-film thicknesses up to ~ 700 nm. Hence, the exact position of the first interface InGaAs/InP at ~ 670 nm for a typical optimized InP laser structure emitting at 1.55 µm. Although the shorter wavelengths (340 nm and 405 nm) do not exhibit clear FPO due to high absorption in InP and its alloys, both reflectance traces show a sharp contrast near the interface enabling accurate detection of the cladding/core interface and therefore etch depth (while not possible at 670 nm), a benefit of using multiple wavelengths. In contrast, the 670nm reflectance transient is well suited for determine the etch rate, which was deduced all InP-alloys as ~ 5.5 nm/sec for InGaAs.

By combining criteria across multiple wavelengths, the EPD recipes can be optimized for various scenarios, from simple to highly specific requirements. The recipe editor within EtchNet allows for the rapid design of EPD recipes, incorporating etch rate determination, depth calculation, and interface detection. Currently, III-V Lab utilizes a combination of FPO counting at 670 nm and a sharp reflectance change at 405 nm, as shown in **Figure 4b**.

From the stop marker location, we estimate a remaining thickness of MQW layer of 2 nm ~ +/- 1 nm at the interface formed by the Multiple Quantum Well (MQW) region and the InP-based lower cladding layer.

The robustness of the EPD algorithm was validated by applying it to samples with the same double heterostructure laser but of different sizes (e.g., a quarter of a 2" wafer instead of a full 2" wafer), using the same etch recipe. Despite significant etch rate changes (typically 30 %) due to sample size, the EPD system efficiently terminated the etch process by identifying the same specific features, ensuring consistent performance.

Conclusion

With TRIton®, LayTec presents a reliable and robust EPD system based on three wavelengths. It enables simultaneous real-time monitoring of etch rates via FPO at longer wavelengths and detection of interfaces using shorter wavelengths. This makes TRIton® ideally suited for dry etching of InP lasers with etch depths from a few nanometers to several micrometers (e.g. 2-3 µm or more), significantly enhancing depth resolution. The improved performance of in-situ metrology for plasma etch monitoring has been tested at the III-V Lab and is currently improving their fabrication yield of InP lasers.

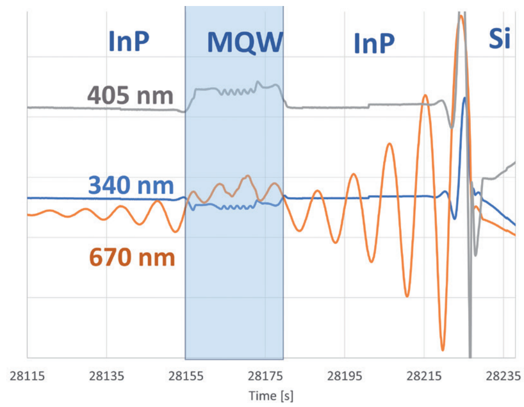

Fig. 4a) Etch transient of an etch through run of a InP-based MQW laser structure recorded with TRIton® showing FPO and interfaces to derive EPD algorithm.

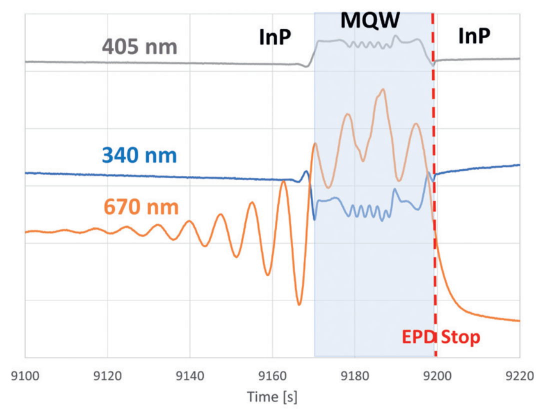

Fig. 4b) Successful EPD at MQW/InP lower cladding layer. EPD algorithm makes use of FPO counting at 670 nm as well as reflectance step change at 405 nm.

References

[1] In-situ endpointing metrology solutions for monitoring dry etch processes,
https://www.laytec.de/solutions/processes/dry-etch
See also: 'PlasmaPro 100 Atomic Layer Etch with Etchpoint',
https://plasma.oxinst.com/products/plasmapro-100-ale-and-etchpoint

[2] "Plasma-Etch Endpointing in InP-Based Laser Device Structures", J. Decobert et al,
https://csmantech.org/paper/6-2-3-2024-plasma-etch-end-pointing-in-inp-based-laser-device-structures/

The "Connected Metrology" approach

The LayTec Connected Metrology® ecosystem enables improved process control characterizing complex layer stacks along the manufacturing chain. In a typical frontend production line, wafers are typically measured multiple times. Using LayTec systems in all of these process steps bears the potential to forward and share the respective analysis data from each step to the subsequent ones, thereby unfolding the full potential of the Connected Metrology® approach. During epitaxy, EpiCurve® TT can determine the thicknesses and composition of many individual layers as well as their in-situ. In the ex-situ wafer mapping with EpiX® C2C by white light reflectance and photoluminescence, full 2D wafer maps are acquired characterizing the 2D uniformity of critical layer thickness, layer composition and other sample properties. During sub-sequent plasma-etching processes, the thickness monitoring and endpoint detection is again performed in-situ by LayTec's TRIton®. As the wafer is advancing through the frontend production line, the amount of information on the particular wafer increases and is combined for improved analysis in downstream processes. By connecting in-situ and ex-situ metrology, we can determine the critical layer parameters of increasingly complex layer structures at die-level.

Connected Metrology®

About us

LayTec, founded 1999 in Berlin, is a major provider of in-situ and in-line optical metrology for thin-film processes.

These metrology tools are used in a broad range of thin-film applications such as LED & laser production, power devices and transistors, thin-film photovoltaics, oxide and organic deposition as well as other large area deposition processes. LayTec's integrated metrology provides access to all key thin-film parameters in real-time – either in-situ, during the deposition process, or in-line. Also, in-situ metrology tools for dry etching have been added expanding LayTec's portfolio along the production chain.

Beyond these integrated methods, LayTec also offers mapping solutions which ideally complement in-situ measurements by providing uniformity analysis of the deposited layers. The implementation of LayTec metrology systems in production processes significantly shortens development cycles and enables an efficient quality control that helps to considerably reduce production and development costs.

LayTec AG Seesener Str. 10-13 | 10709 Berlin, Germany | Tel.: +49 (0)30 89 00 55-0 | Fax: +49 (0)30 89 00 55-180 | Email: info@laytec.de | Web: laytec.de