

# Rapid, Semi-Quantitative Elemental Depth Profiling Using Plasma Profiling Time-Of-Flight Mass Spectrometry

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## INTRODUCTION

Plasma Profiling Time-Of-Flight Mass Spectrometry (PP-TOFMS) is a novel elemental depth profiling technique developed by Horiba Scientific. It couples an argon plasma source for sample sputtering and ionization with an orthogonal time-of-flight mass spectrometer. The technique delivers nanometer-scale depth profiles with high sensitivity and is capable of providing calibration-free semi-quantitative results. Moreover, the operation of the instrument is simpler and faster compared to typical SIMS instruments requiring only a few minutes including sample introduction and pumping.

The instrument is installed in a cleanroom at CEA-Leti in close proximity to process tools allowing fast feedback for materials development. The potential of this technique will be illustrated by several examples...

## INSTRUMENTAL CONDITIONS

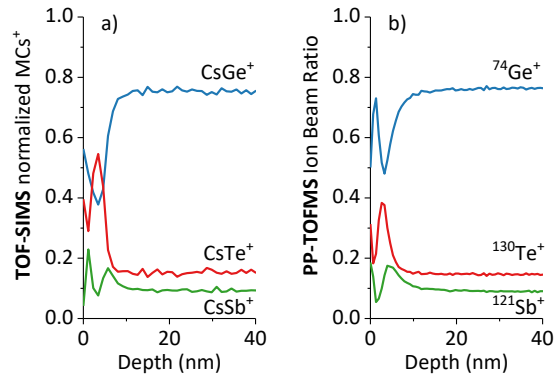
The PP-TOFMS technique couples a plasma source for sample sputtering and ionization to an orthogonal time-of-flight mass spectrometer. The plasma source uses a pulsed RF argon discharge allowing the analysis of conducting as well as insulating materials. It is typically operated at pressures around 150 Pa with an applied power of a few tens of W. Under such conditions, the sputtering rate is around 10 nm/s and the sputtering crater diameter is 4 mm. While ions are extracted continuously, counting is commonly done during the power off time where Penning ionization occur<sup>1</sup>. Penning ionization is far less selective than direct ionization, allowing semi-quantitative analyses via the Ion Beam Ratio method<sup>2</sup>. Mass spectra are easy to read as the technique mostly produces monoatomic ions. The instrument can be open to a wide range of users as user training is quick and operation is simple. This technique can therefore be used upstream of more complicated and time-consuming SIMS measurements.

## APPLICATIONS

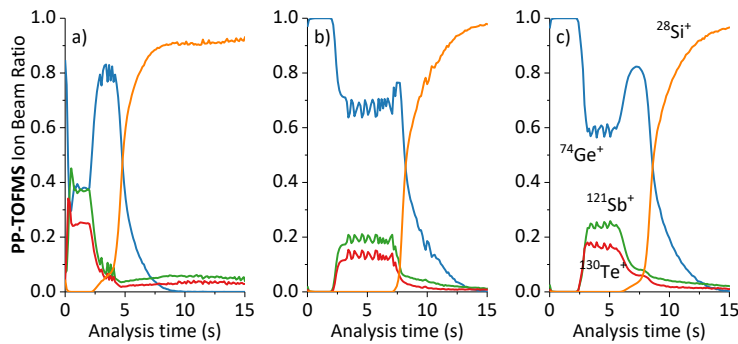
### GeSbTe thin films for memory applications

Phase change random access memory (PCRAM) is a technology based on the reversible transition between a highly electrically resistive amorphous phase and a low resistivity crystalline phase of chalcogenide materials. PCRAM are already produced in advanced fabs (e.g. in Intel 3D XPoint product line) and extensive research is being conducted to improve their properties. Material properties, such as temperature stability or crystallization conditions are composition driven. Precise control of in-depth composition is thus critical for material engineering.

Figure 1 (a) illustrates the very good agreement on elemental depth profiles obtained with well-established time-of-flight mass spectrometry (TOF-SIMS) and PP-TOFMS measurements. The technique was extensively used to support the material development<sup>3</sup>, in particular to study the effect of passivation layers to maintain a Ge-rich composition after annealing as presented Figure 2.



**FIGURE 1.** Chalcogenides atomic fractions estimated using TOF-SIMS (a) and PP-TOFMS (b).

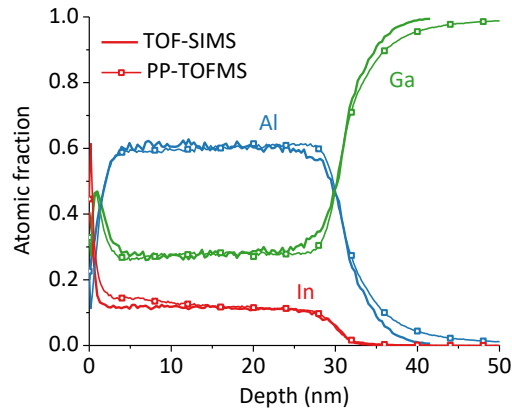


**FIGURE 2.** PP-TOFMS depth profiles of Ge-rich GeSbTe thin layers: after annealing without passivation layer (a), with the passivation layer (b) before and (c) after annealing.

### InAlN barrier layers engineering for power applications

Due to their outstanding properties and high performance, III-nitride materials based on GaN, AlN, InN and their compounds are increasingly being used in the manufacture of high-power and optoelectronics components. However, the growth of high-quality ternary or quaternary alloys can be challenging as many process parameters need to be optimized.

We focus here on the production of InAlN barrier layers grown in close-coupled showerhead metal-organic vapor phase epitaxy (MOVPE) reactors. Figure 3 shows a superposition of PP-TOFMS and SIMS profiles for an InAlN layer on GaN. The profiles from the two different techniques match very closely in terms of Al, Ga and In relative composition<sup>4</sup>. This allowed PP-TOFMS profiling to be used instead of SIMS to give quick feedback about changes in process conditions to obtain an optimized recipe to minimize Ga content in InAlN layers in a showerhead reactor in a few weeks<sup>5</sup>.



**FIGURE 3.** Depth profiles obtained using calibrated PP-TOFMS and TOF-SIMS measurements.

### Conclusions and perspectives

In conclusion for these two cases PP-TOFMS has been shown to be complementary to SIMS analysis and is particularly useful as a cleanroom-based tool for rapid elemental depth profiling accessible by a wide user base. It may also be used to identify unknown contaminants as the mass spectra contain less molecular ions than in TOF-SIMS and are thus easier to interpret. This technique is currently being tested on a wide range of semiconductor applications.

### REFERENCES

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### KEYWORDS

Depth profiling, PP-TOFMS, SIMS, TOFMS, Memory, III-N materials