New Platform for Multimodal Spectroscopic Characterization of Semiconductors

半導体のマルチモーダル分光分析のための新しいプラットフォーム

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Multimodal spectroscopy is the concept of combining several different spectroscopies onto one platform, thereby expanding the range of analytical capabilities available on that single platform. In advanced semiconductor fabrication, the need to streamline production and avoid unnecessary wafer handling makes it quite common to have several different metrologies at one wafer processing station. However, this concept is still not common at the material research or product & process development stages where it is more common to have several different instruments offering different analytical spectroscopies. Besides the obvious benefit of cost reduction, having multiple analytical spectroscopies offers the added benefit of sample co-location so that multiple complementary measurements can be made at the same location of the sample. The benefit of co-location is particularly important as feature sizes get smaller, from a few microns to nanometers in size. We show results from a multimodal microspectroscopy system from HORIBA for semiconductor characterization. The Standard Microscope Spectroscopy (SMS) system is a modular and flexible system capable of accommodating up to seven different spectroscopies, including Raman, Photoluminescence, Time-resolved Photoluminescence (Lifetime), Reflectance and Transmittance, etc. Furthermore, we show that even when there is a need to perform correlative measurements across different instruments, it is possible to use coordinate system transformation technologies, such as nanoGPS navYX™ from HORIBA to rapidly achieve sample co-location across different measurement platforms.

Key words
multimodality, wafer handling, speed, cost minimization, reproducibility

マルチモーダル分光法は，複数の異なる分光法を1つのプラットフォーム上で組み合わせるというコンセプトで，単一のプラットフォームで利用できる分析機能の範囲を拡大する。最先端の半導体製造では，生産の効率化と不必要なウェハーハンドリングを避けるために，1つのウェハープロセスステーションに複数の異なる測定器を設置することがごく一般的になっている。しかし，材料研究，あるいは製品やプロセス開発の段階では，このコンセプトはまだ一般的ではなく，異なる分光分析法を提供する複数の異なる装置を持つことがより一般的である。複数の分光測定技術を集積することで，コスト削減という明らかなメリットに加えて，サンプルの同じ場所で複数の補完的な測定が可能になるという利点もある。このような同一特定場所でのマルチ計測は，デバイスの微少部分や欠陥等の特性把握において，特に重要になる。ここでは，半導体特性評価のために，HORIBA製マルチモーダルマイクロ分光器システムから得られる結果を紹介する。SMSシステムと呼ばれるこのシステムは，ラマン，フォトルミネッセンス，時間分解フォトルミネッセンス（ライフタイム），反射率，透過率など，最大7種類の分光法を搭載できるモジュール式のフレキシブルなシステムである。さらに，異なる装置間での相関測定が必要な場合でも，HORIBAのnanoGPS navYX™のような座標系変換技術により，異なる測定プラットフォーム間でのサンプルコロケーションを迅速に実現することが可能であることを紹介する。

キーワード
マルチモダリティ，ウェハーハンドリング，スピード，コスト最小化，再現性

Introduction

Semiconductor devices are some of the most complex engineered devices in today's world. Their manufacture often requires an even more complex sequence of steps, first to understand and tailor the material properties so that desired electrical, optical or mechanical properties are possible, followed by very intricate and controlled fabrication processes so that devices are reproducible and reliable, and at a reasonable cost. The above sequence of events demands that the practitioner is able to measure the material and device properties at every step of the design and production process to ensure that yields are optimal, and to remove defective material or components as early as possible in the production process, as every step adds cost and complexity.[1] A vast number of techniques have been developed for these types of material, product and process characterization. Amongst these, optical or spectroscopic techniques are usually preferred. The preference for optical spectroscopy in semiconductor material and process characterization derives from several factors. Optical spectroscopic (OS) techniques are often non-contact, hence reducing the chances of contamination. Secondly, many OS techniques are comparatively fast and require little to no sample preparation.

Given the large number of material and process parameters that can affect the behavior of the final semiconductor product, it follows that control of the material design and fabrication process is necessarily a multimodal effort. This means that many measurement techniques are required to measure and control all the parameters that lead to desired device behavior. Instrument vendors have accordingly developed a wide variety of specialized optical spectroscopy instruments often specialized on each of the required techniques. In addition, as device features go from micro to nano, many of these instruments are based on a microscope or other submicron to nanometer measurement platform. For example, it is common in a semiconductor research or fabrication facility to have one micro-Raman spectroscopy instrument used to characterize crystallinity of epitaxial deposition or stress, and a separate photoluminescence instrument to measure wafer homogeneity, etc. Beyond the cost burden of having multiple instruments to perform these necessary measurements, the task itself, in going from instrument to instrument, has become quite challenging recently, as the features of interest become smaller and approach the micro to nanoscale.

In this article, we describe a novel approach to achieve multimodality on one microspectroscopy platform (Figure 1), enabling the practitioner to characterize various semiconductor samples using different spectroscopies with the benefit of sample co-location. In this approach, various complementary measurements can be performed at the same micro location and in so doing, obtain deeper insights into the sample or process. In addition, when there is a necessity to perform micro or nano measurements across different instruments, we present a new coordinate transformation technology (nano-GPS) that enables fast and accurate location of nanostructures across different measurement instruments.

Figure 1 HORIBA multimodal, Standard Microscope Spectroscopy (SMS) system equipped with 12-inch wafer stage.

Example 1: LEDs

One of the most important considerations of LEDs is the emission wavelength. For example, most common Lidar sources have semiconductor materials designed to have light emission at 905 nm or 1550 nm. The primary material property that controls this parameter is the optical bandgap, which is readily measured using micro photoluminescence (Figure 2a). After the material properties are understood, a fabrication process engineer could be

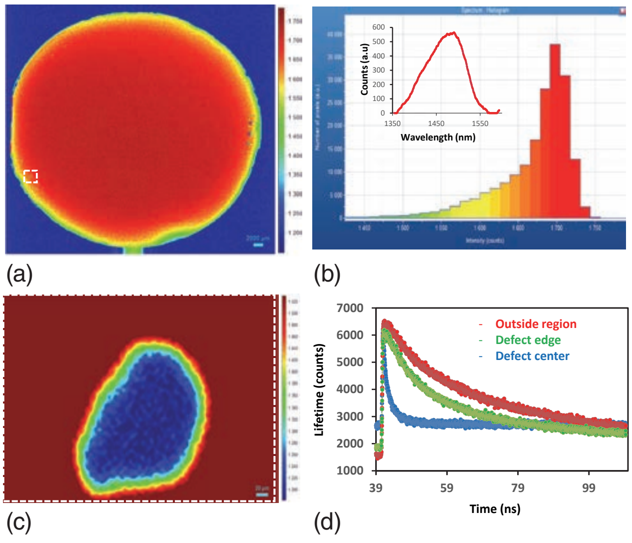
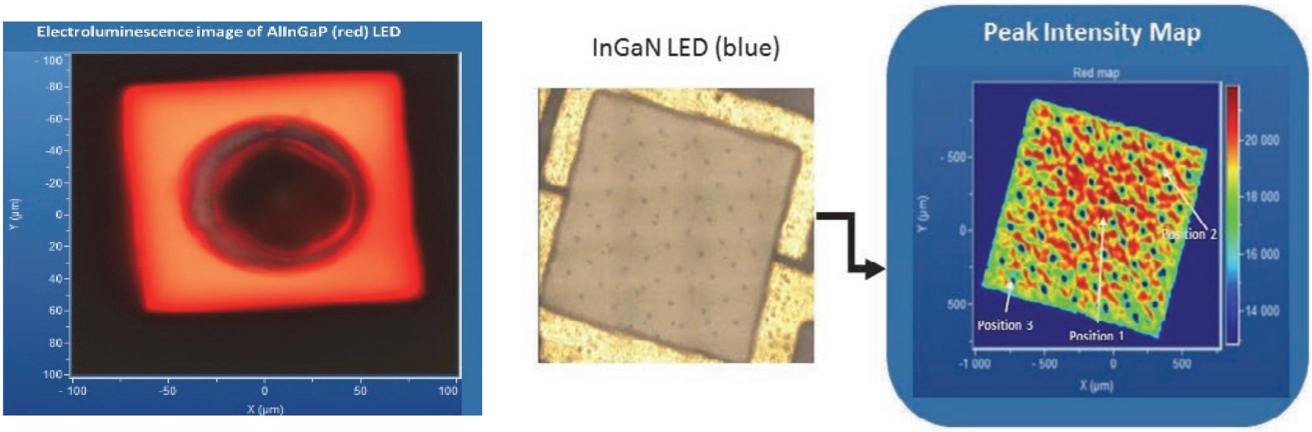


Figure 2 (a) Photoluminescence (PL) map on a InP wafer. (b) PL spectrum (insert) and histogram showing intensity distribution- an indication of homogeneity. (c) High resolution PL map on a defect region (dotted square on (a)). (d) PL lifetime decay curves recorded at three different locations on a defect.



(a) (b) (c)

Figure 3 (a) Representative electroluminescence image of AlInGaP LED and (b) Optical micrograph and (c) PL intensity map recorded from a InGaN LED. Defect region appeared as cold spots on PL map.

interested in the uniformity of the epitaxial deposition on a large wafer, so that a Lidar laser die cut from one part of the wafer can be expected to perform and behave as one from any other part of the wafer. Once again, this property is readily characterized using a photoluminescence (PL) intensity distribution across the wafer (Figures 2a and b). If, for some reason, some of the dies from this wafer do not show optimal luminescence compared to others, the process engineer might be interested in understanding the nature of the defects causing this sub-optimal luminescence efficiency (cold spots). Figure 2c shows a high resolution PL map of a defect. Sometimes, the charge carriers are captured at the defect sites and don't emit light.[2] Time-resolved PL sheds more light on defect properties.[3] Figure 2d shows PL lifetime decay curves from three locations close to a defect. At the defect center, significantly shorter lifetime was observed.

As part of a QA process, the engineer might want to measure the performance of the device under conditions similar to actual use by measuring the electroluminescence of the device before it is packaged (Figure 3a). PL mapping can also be used to analyze the final device as well. Figure 3 (b-c) shows results from an InGaN LED sample, where the PL map detected local luminescence variations.

Example 2: Photovoltaics

Development and fabrication of Photovoltaics show a similar need for multimodal characterization. For example, at the material stage it is important that the material bandgap be engineered to optimally absorb the solar spectrum. Once again, PL is a good technique for determining that property (Figure 2a). The photovoltaic effect relies on the efficient movement of charge carriers either to the electrical load for use or to a battery for energy storage. Time-resolved PL is often used to characterize carrier dynamics (Figure 2d) or Raman spectra to determine micro crystallinity (which in turn affects carrier dynamics (Figure 4a)). Finally, in the QA process of the solar cell device, one might be interested in measuring the overall device efficiency by measuring the spectral photocurrent response (Figure 4b).

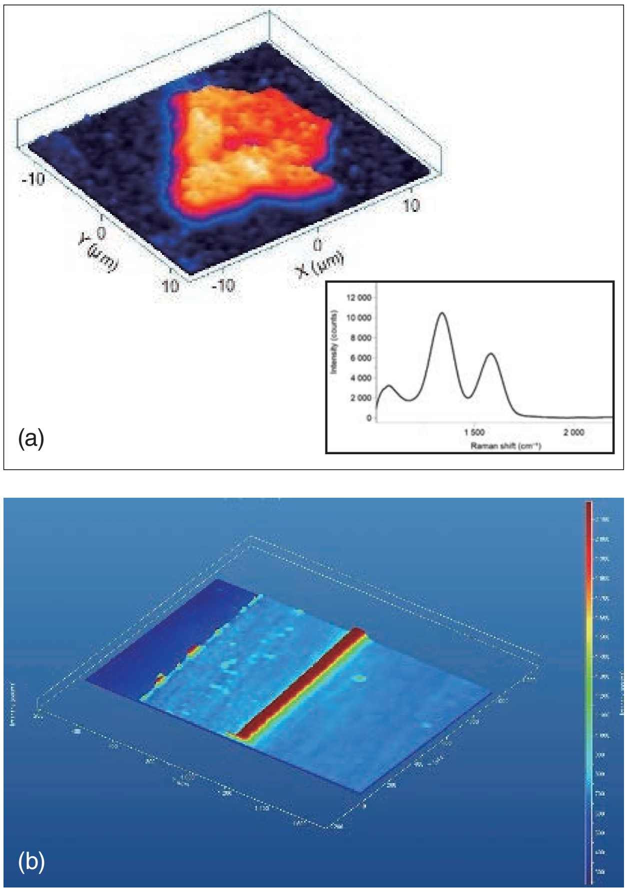


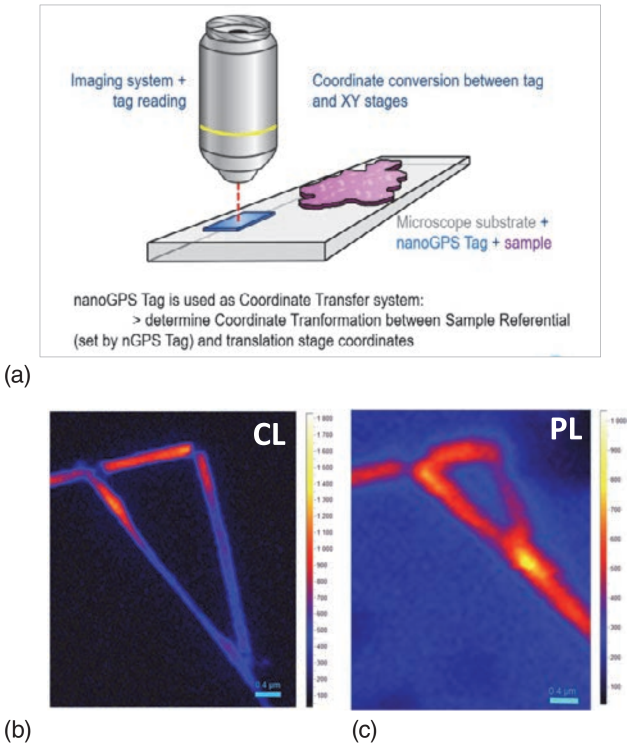
Figure 4 (a) Raman map and spectra (insert) of a possible contaminant flake on the surface of a semiconductor sample. (b) Photocurrent map of a sheet of Silicon PV material showing hot spots (possible defects). The red strip is a piece of the conducting electrode.

Although contrived, the above measurements are typical occurrences in the design and manufacture of LED and

PV devices, and it is also common to see that all these measurements are typically made on different instruments. The novelty in this paper is showing that they can be made on one instrument (the SMS system from HORIBA), resulting in cost savings and adding convenience to the process.

Correlative spectroscopy on semiconductor materials:

Simple, fast and non-contact microspectroscopy techniques such as the ones described above, are usually preferred in semiconductor material characterization, but it is sometimes necessary to use other, more complex, techniques that are not easy to combine with the above. For example, defect characterization sometimes requires high spatial resolution (nanometers) that is only available on instruments such as a scanning electron microscope (SEM) or an atomic force microscope (AFM). In those instances, and due to the cost and complexity involved in using a specialized instrument such as an SEM, it is desirable to establish a correlative optical spectroscopy so that such a defect can be identified in the future using a simpler spectroscopic technique, rather than doing the measurement on an SEM repeatedly, which can be costly and slow. To achieve this correlation, it becomes necessary to identify a nanoscale feature in the SEM, and to also be able to identify the same feature under an optical microspectrometer which can be laborious and time-consuming without some type of coordinate system matching between the two instruments. To facilitate this process, automated nanoscale coordinate transformation technologies, such as nanoGPS navYX^{TM} from HORIBA have been developed to enable fast, accurate and repeatable localization of nanoscale objects between different measurement systems (Figure 5a). Figure 5c shows the cathodoluminescence map recorded from a Ga_2O_3 nanostructure. Using nanoGPS, the sample was transferred to a HORIBA SMS system and a PL map was recorded successfully (Figure 5c).



(a)

(b) (c)

Figure 5 (a) Schematic illustration of nanoGPS tag attached to the sample facilitates seamless coordinate transfer between two analytical systems. (b) Correlative cathodoluminescence (CL) and (c) PL measurements performed on a Ga_2O_3 nano structure.

Conclusion

In conclusion, speed, cost minimization and reproducibility are persistent drivers for decision making when it comes to instrumentation choices for semiconductor research and fabrication. In this paper, we introduce a novel modular and multimodal platform that enables the efficient combination of several complementary spectroscopic techniques relevant for semiconductor characterization on one platform. Furthermore, and for when it is necessary to measure across different platforms, we introduce a new coordinate transformation technology that enables the fast and accurate localization of nanoscale features across different measurement and metrology platforms. For further information about the different spectroscopies available on such a platform, please visit www.microspectroscopy.com and download the application handbook.

* Editorial note: This content in based on HORIBA's investigation at the year of issue unless otherwise stated.

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