Metrology

Navigating Wafer-thin Margins with Vibrational Spectroscopy

RUI CHEN, PH.D., Senior Manager, Applications, Thermo Fisher Scientific

State-of-the-art vibrational spectroscopy analyzers are becoming increasingly intuitive and user friendly, removing many of the obstacles that have historically made routine use of these techniques arduous for individuals with limited expertise.

SEMICONDUCTORS ARE AT THE HEART of the transition from an analog to a digital world, which is now reaching almost every sector, from finance and medicine to transportation and education. Delivering the next generation of semiconductor performance is not without its challenges, as the continuing rise of artificial intelligence, machine learning and the Internet of Things is putting immense pressure on the industry to create smaller, more powerful and more energy efficient devices. These factors, coupled with the desire for greater affordability, are driving new innovations in advanced semiconductor device design, construction and packaging.

Fabricators must quickly increase their understanding and application of material structures, wafer processing, thin-film deposition approaches and interface preparation to get the most out of existing silicon technologies. This includes improving the fabrication of nanostructures and architectures with uniform dimensions, which are vital for developing semiconductor devices with greater performance and functionality. For example, semiconductor coatings are critically important for semiconductor functionality, with manufacturers moving towards thinner coatings with greater homogeneity. Even minor faults or inconsistencies during manufacture may influence product yield or performance for these more advanced structures. For instance, metal shorts, opens or transistor-level leakages can cause semiconductor devices to fail at end-of-line tests, with high density interconnects, wafer-level stacking, flexible electronics and integral substrates making it increasingly difficult to detect failure-inducing defects. These failures can occur at the packaging stage, resulting in a potentially catastrophic loss of yield, and a dramatic increase in time-to-market.

Manufacturers understandably want to catch any issues as soon as possible in the R&D and fabrication processes—avoiding unnecessary time and financial losses to maximize profit margins—putting pressure on quality control (QC) processes. Implementing highly accurate, non-invasive inline analysis throughout the entire manufacturing workflow is therefore vital, helping to pick up defects early on to shorten device development time, maximize yields, and ensure that semiconductor devices are within spec and meet the evolving needs of the industry's diverse customers. The smaller sizes and novel materials used in semiconductor fabrication push traditional metrology methods to their limits, and customers are also looking to analyze a greater number of samples faster than ever before, presenting challenges in the design of instrumentation and data processing software. This highlights the need for alternative analytical solutions with improved spatial resolution and versatility that are adequate for characterizing new materials and miniaturized semiconductor components.

A broad spectrum of analytical technologies

Vibrational spectroscopy techniques—such as Fourier-transform infrared (FTIR) spectroscopy and near infrared (NIR) spectroscopy—have been widely used in R&D, fabrication and QC in the semiconductor industry for several decades. FTIR is primarily used for detecting elemental impurities and defects in silicon during manufacturing, with well-defined workflows and fit-for-purpose data reporting. It is also an excellent choice of technique for the analysis of ultra-high purity gases used in semiconductor manufacturing. In addition, there has been an increase in the use of FTIR spectroscopy for the development of new semiconductor materials in recent years, aiding in the rapid determination of critical parameters such as the bandgap, lattice vibrations, layer thickness and doping concentration. On the other hand, NIR spectroscopy can be used in combination with chemometric algorithms to monitor the concentrations of the multiple component solutions used in etching and cleaning, providing reliable *in situ* data that can be used to fine-tune processes, and resulting in more efficient use of materials while still maintaining high product yields. Non-invasive sampling through fiber optic cables allows remote placement of the analyzer and offers multi-point capabilities.

Shining a light on Raman spectroscopy

Raman spectroscopy is widely recognized in the semiconductor industry as a complementary technique to infrared analysis, but is primarily limited to laboratory applications. However, the industry is actively exploring new designs, operating principles and approaches to meet the increasing performance demands, and is seeking to incorporate novel materials and compounds. The rapid diversification of the materials and methodologies used in the semiconductor fabrication process is also causing manufacturers to adopt alternative metrology systems. Raman spectroscopy is ideally suited for characterizing a wide range of new semiconductor compounds, including silicon, carbon-based, group III-V alloys and polymers, which all exhibit distinct Raman bands. As a result, Raman spectroscopy can provide a wealth of information about analytes, such as chemical compositions, polytypes, stress and strain analyses, dopant concentrations, crystal structure types and orientations, uniformities and purities. The great advances made in Raman microscopy enable the characterization of semiconductor devices with a high spatial resolution – down to below a single micron – and these strengths are encouraging producers to gradually bring Raman spectroscopy to the forefront of their inline analytical approaches.

Accessible analysis for enhanced efficiency

Today's analytical technologies must evolve rapidly to keep up with the sector's shift away from specialism to generalism, meaning that instruments must be easy to operate by non-experts and feature a high level of automation for enhanced throughput. State-of-the-art vibrational spectroscopy analyzers are becoming increasingly intuitive and user friendly, while still offering high performance, removing many of the obstacles that have historically made routine use of these techniques arduous for individuals with limited expertise or specific technical knowledge. These developments make Raman and FTIR accessible to a wider operator base in daily workflows, lightening the workload on more experienced team members and helping to speed up analyses for faster throughput. These highly sensitive complementary technologies therefore hold much potential for greatly streamlining semiconductor design and production, by offering unparalleled insights into the performance of novel materials and enabling the early detection of more defects during manufacturing.