Raman Spectroscopy Applications
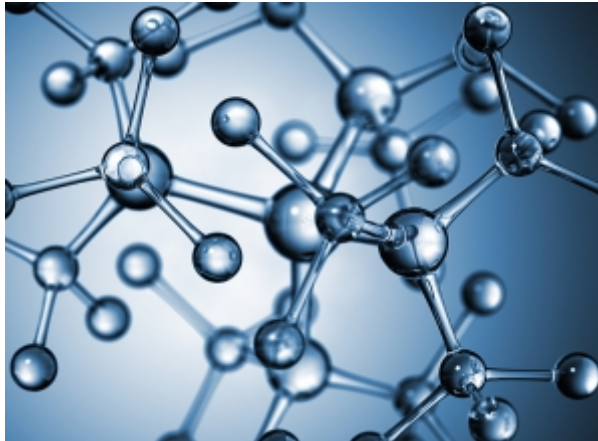

Raman spectroscopy utilizes inelastic scattering of photons off of covalently bound molecules to identify functional groups, crystallinity, and stresses and strains. It is a widely used tool in the spectroscopy community for both quantitative and qualitative molecular analysis, with applications ranging from high-end university research to airport security screening. Because of the extensive range of applications for Raman spectroscopy, it can often be confusing to determine which spectrometer is best suited for any given application. To help alleviate this challenge this application note will provide an overview of three common applications, biomedical diagnostics, silicon wafer stress monitoring, and incoming material verification, along with suggestions of a preferred spectrometer for each application.

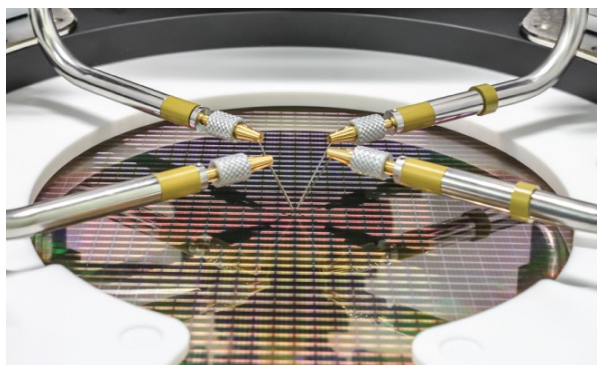Doctor performing an endoscopy procedure

Medical Diagnostics

Raman spectroscopy has been repeatedly shown to have massive potential for point-of-care medical diagnostics and monitoring due to its ability to provide a non-contact non-destructive molecular fingerprint of many common physiological biomarkers. In the field of cancer detection alone there have been thousands of research papers published ranging from applications such as interoperative cancer boundary detection during breast, brain, and oral tumor removal to urine testing for monitoring lung cancer response to treatment. Not only are most common biomolecules, such as nucleic acids, proteins, lipids, and fats highly Raman active due to their nonpolar molecular structure, but perhaps, more importantly, the abundance of water in these samples does not interfere with the spectra due to the extreme polarity of water molecules. This dichotomy between the scattering cross-sections of biological macromolecules and water is what allows Raman to be used on both tissue and bodily fluids for the identification of pathogens, blood disorders, cancers, and other abnormalities.

Because of the complexity of biological molecules, they tend to produce much broader spectral features than most other Raman active molecules. While this lends itself to a reduction in overall signal efficiency requiring longer integration times, it also means that the spectral range and resolution requirements of the device are often quite relaxed. This is particularly evident in fit-for-purpose instrumentation which is designed to only look at a select few spectra features. For this application a spectrometer such as the AvaSpec-Hero, model number AvaSpec-1024X58-HSC-EVO, due to its deep cooling and high-sensitivity back-thinned CCD detector. Additionally, the AvaSpec Hero also boasts an extremely wide dynamic range of 40,000:1, which makes it much easier to detect the subtle variations which can often mean the difference between healthy and diseased tissue.

Silicon Wafer Testing

Another up and coming Raman application, particularly in the photovoltaics' industry, is the monitoring of both stresses and crystallinity in silicon wafers. Pure crystalline silicon is far more effective than its amorphous counterpart at converting light into electricity, and because of this, it is utilized in the production of over 85% of the commercially available solar cells on the market today. Crystalline silicon is capable of producing conversion efficiencies of ~20%, while by comparison, amorphous silicon solar cells offer less than 10% efficiencies as of

A wafer testing system at work

today. As a result, quality control of these devices is critical at the wafer level to ensure peak performance. Raman spectroscopy is an ideal tool for the job, since the effect is polarization sensitive, the orientation of the silicon molecular structure will affect scattered Raman spectra. For pure crystalline silicon, there is only one allowed molecular vibration resulting in a single narrow spectral peak at $521cm^{-1}$ but in the case of amorphous silicon where the molecules are randomly oriented the band shifts and broadens resulting in an extremely wide peak centered at $480cm^{-1}$. Additionally, even if the wafer is made of pure crystalline silicon, but has undergone stresses or strains during the manufacturing process, it will also decrease the solar cell's efficiency and lifetime. This stress results in the molecular bonds being dampened causing slight changes in the vibrational frequency which can be detected by looking at the shift in the Raman peak.

For both of these applications, sensitivity is usually not a concern due to the large Raman cross-section of silicon, but high resolution is critical to detect the small shifts in the $521cm^{-1}$ peak from stresses and strains. It is also important to note that silicon is unique for having a photoluminescence peak in the near infrared, making it preferable to use visible wavelength excitation lasers, further increasing the Raman scattering efficiency of the system. As a result, it is recommended to use the AvaSpec-ULS2048X64-TEC, high-resolution TE cooled spectrometer which is capable of $3cm^{-1}$ resolution in the visible range of the spectrum. Avantes' proprietary high-speed electronic triggering, data transfer rates, and analog and digital I/O capabilities further aide in this unit's ability to seamlessly integrate into a high-speed wafer inspection system.

Incoming Raw Materials Inspection

Incoming Inspection

The last application which will be explored is incoming material inspection for pharmaceutical and nutraceutical manufacturing which utilize the same fingerprinting ability of Raman spectroscopy as described in the biomedical section above. Over the past ten years, this application has, in part, lead to the explosion of handheld Raman systems which can be seen on the market today because of its ability to rapidly speed up material verification process allowing raw materials to pass from the quarantine area to the production floor quickly. This is typically accomplished by integrating the laser, spectrometer, and data processing unit all into a single handheld device with embedded chemometrics for verifying the identity of active pharmaceutical ingredients (API's), excipients, and other pharmaceutical ingredients. Raman is ideal for this application because the laser can be focused through optically transparent packaging allowing for the contents to be analyzed without ever opening the product and exposing its contents to the environment.

For integration into a handheld instrument, size is one of the most critical design considerations, which is why the AvaSpec-Mini-2048CL is the spectrometer of choice for many handheld instrumentation manufacturers. The AvaSpec Mini weighs in at only 175 grams at compact size of just 95mm x 68mm x 20 mm which is roughly the size of a deck of playing cards, and because of the highly efficient 2048-pixel CMOS linear array detector, this

unit draws less than 2.5 watts of power. The AvaSpec-Mini is produced with the latest in automated production technology, providing excellent unit-to-unit reproducibility and temperature stability, which is critical for customers who are looking to for the ability to transfer methods from one handheld instrument to another.