< This false-color image depicts an interferogram in the visible spectrum taken by a CMOS camera. It contains spectroscopic information from the mid-wave infrared range which was translated into a visible image using correlated photon pairs.

GROUP **NONLINEAR OPTICS AND QUANTUM SENSING**

Quantum sensors: Measuring with entangled photons

Effects seen in the quantum world open up surprising opportunities for measurement technology, too. The properties of entangled photons can be used in spectroscopy, for instance, to gather valuable spectral information from wavelength ranges which are otherwise difficult to access. Fraunhofer IPM is working together with other Fraunhofer institutes on the continued development of cutting-edge quantum sensor-based measurement technology targeted at potential industrial application.

Research in quantum mechanics has resulted in a series of scientific breakthroughs in the past years. In science, politics and industry, this is known as the second quantum revolution, in which quantum technology is emerging as a key technology in our modern information society. Unlike with the first generation of quantum technologies, which was based on the use of large ensembles, individual quantum systems can now be prepared, manipulated, transmitted and measured in their entanglement and in superposed states.

Quantum sensor technology – new measuring potential

Quantum sensor technology refers to sensor technology which is capable of measuring physical parameters by exploiting the specific properties of isolated quantum systems. This can involve atoms in specially prepared electronic states, localized states in solids, or photons whose properties are “entangled.” On account of the methods they employ, quantum sensors and the measurement systems based on them are often more complicated in their construction than traditional sensors. But they do have significant advantages in terms of sensitivity and measuring accuracy, the best-known example being the development of atomic clocks using ultracold atoms.

Entangled photons enable the development of new measurement technologies for imaging and spectroscopy. To make this happen, a nonlinear optical medium – a crystal with special physical properties – is excited by suitable laser light, causing single photons from the laser beam to be converted in a parametric process into correlated pairs consisting of two entangled photons. Each pair of entangled photons can be seen as a singular quantum system. Thus, their properties are extremely closely correlated. This means that measuring a property of one photon in the pair gives a direct indication of the corresponding property of its partner photon.

Particularly interesting for spectroscopy is the possibility of creating these entangled photon pairs with different wavelengths, allowing us to obtain valuable spectral information from difficult-to-access wavelength ranges. The key is that, with this method, the spectral information is carried not just by the photon which interacts with the sample, but also by the correlated partner photon.

MIR spectroscopy with entangled photons

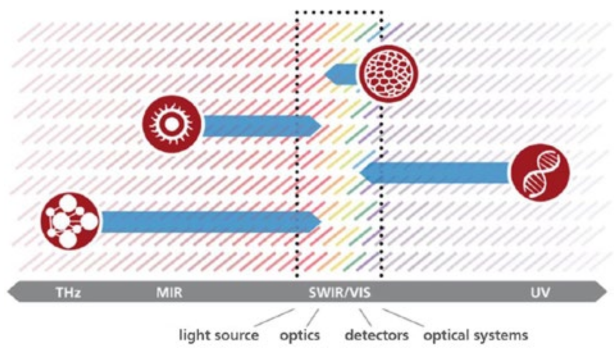
The mid-wave infrared (MIR) range is often described as the fingerprint region, since many materials can be particularly well detected and differentiated in this wavelength range between approximately three and 15 micrometers, where they exhibit characteristic absorption bands. Yet there is one problem – this spectrum requires sophisticated lasers, and suitable detectors for the MIR range are technically complex and expensive.

So the team at Fraunhofer IPM relies on an alternative approach in which the photon pairs each comprise one visible photon and one mid-wave infrared photon. The infrared photons interact with the sample to be examined. The visible partner photons then make it much quicker and easier to access spectroscopic information in greater detail with measurement techniques using standard detectors or cameras.

A novel field of work with great potential

Contrary to other areas of quantum sensor technology, the use of such spectrally widespread photon pairs for spectroscopy is still a new field of work. Fraunhofer IPM is actively involved in an early phase of research aimed at using its own work to explore this technique’s potential for possible spectroscopic and analytical applications and later harnessing it for industrial solutions. This work is part of Fraunhofer’s QUILT lighthouse project.

The goal of Fraunhofer’s **“QUANTUM METHODS FOR ADVANCED IMAGING SOLUTIONS” (QUILT)** lighthouse project is to implement the findings of quantum technology research in innovative components and systems as well as in functional demonstrations. QUILT is focused on the field of quantum imaging, where non-classical states of light are used to implement new imaging and spectroscopy methods. The project is coordinated jointly by Fraunhofer IOF and Fraunhofer IPM. Four other Fraunhofer institutes belong to the consortium. The project has been ongoing since September 1, 2017, and is set to be completed by August 31, 2020.



Correlated pairs of photons with a broad spectrum of wavelengths allow for easier detection of spectral information in the ultraviolet (UV), mid-infrared (MIR) and terahertz (THz) ranges. Silicon detectors gather the spectroscopic information by measuring a correlated photon in the visible spectral range (SWIR/VIS).

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