Tomography for plasmonics

Tomography is an imaging technique that allows the reconstruction of a three-dimensional object from a collection of two-dimensional projection images. Images of almost any type can be used as long as the relationship between the two-dimensional projections and the object properties are known and satisfy the projection theorem: the image contrast should vary linearly with the property of interest of the sample. Because of its generality, tomography, envisioned by Johan Radon in 1917, has been widely used, from probing the internal structure of the Earth to imaging the internal organs of living organisms. Now, writing in *Nature Nanotechnology* Ashwin Atre and co-workers from Stanford University and the FOM Institute AMOLF in the Netherlands show that tomography can be utilized to image plasmons in nanoscale objects using two-dimensional cathodoluminescence projections.

Imaging plasmon modes at the nanoscale is extremely challenging because the physical dimensions of the objects are much smaller than the wavelength of the light coupling to them. Researchers, therefore, have tried to use shorter-wavelength radiation, such as electron beams as used in cathodoluminescence (CL) and electron energy-loss spectroscopy (EELS). In CL imaging, a small electron beam probe is placed at a known location within the object; the electron beam excites the sample and the light emanating from the object is then detected in the far field, as shown in Fig. EELS, on the other hand, analyses the energy of the electrons that pass through the sample offering good spectral and spatial resolution, as well as good collection efficiency. Detecting the emitted light by CL has the advantage that the spectral resolution usually exceeds that achievable by analysing transmitted electrons. The fact that EELS, unlike CL, probes all excitations means that radiative (light-emitting) and non-radiative modes cannot be discriminated. Comparing CL and EELS spectra offers this possibility. Alternatively, resolutions better than the wavelength of light can be achieved by collecting the emitted light in the near field, but this requires a complicated apparatus and may not be suitable for tomographic imaging.

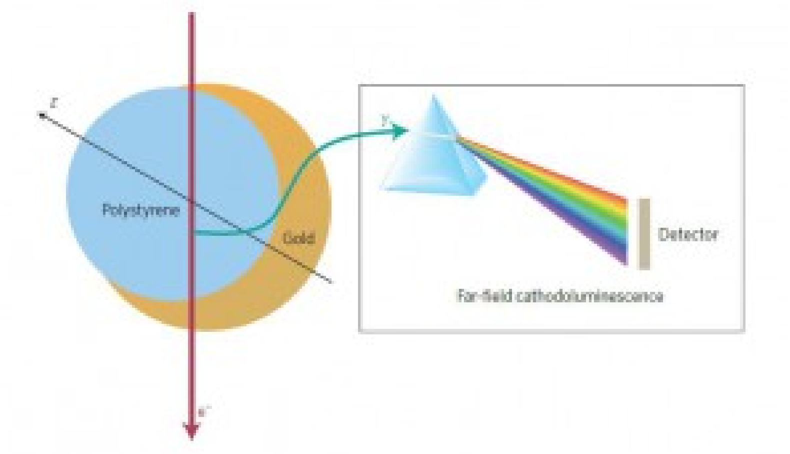

Fig :   Cathodoluminescence signal collection in a scanning electron microscope. A focused electron beam (red) is stepped over a nano-crescent made of a polystyrene core and gold shell. The light (gamma) generated by the incident electron beam at each position is linked to the plasmonic excitations at that location and can be collected by a spectrometer. The nano-crescents studied by Atre and colleagues are rotationally symmetric around the *z* axis. The symmetry reduces the requirements for the number of projections needed to reconstruct a three-dimensional representation of the plasmonic modes. For objects where the mutual orientation of the electron beam and the object has no effect, a single projection image is sufficient to generate a virtual tilt series that can be used to reconstruct the object in three dimensions. For plasmons, the mutual orientation of the beam and the excited object needs to be taken into account, in principle requiring a large set of projections. Nevertheless, Atre and colleagues achieve a good agreement between simulations and the plasmonic excitation map obtained from only seven projections.

A drawback of CL is the poor light-collection efficiency, as only a small fraction of the light generated by the electron beam reaches the detector. This fact, combined with the limited brightness of electron sources leads to data acquisition times that make collection of a standard tilt series of projection images for tomography impractical.

Moreover, extensive electron-beam irradiation can damage the sample. Atre and colleagues circumvent these challenges by preparing crescents randomly oriented on a substrate and then only acquiring the projection that is at 90° with respect to the electron beam. From this single projection, the researchers generate, using a computer algorithm, a full standard tomographic tilt series by taking advantage of the symmetry of the object. The three-dimensional tomographic reconstruction is then performed using traditional filtered back-projection of this virtual tilt series.

The price to pay for this significant reduction in data collection is that not all of the plasmonic modes may be detected. For a particular mode to be excited, a favourable orientation of the nano-crescent and the electric field associated with the incident electron beam is necessary. Collecting CL images from several nano-crescents with suitable orientation reduces or eliminates the possibility of missing an image of an excitation mode. When CL spectra are collected in a scanning (transmission) electron microscope the CL signal is integrated along the entire electron-beam path within the imaged object. As a result, the CL signal can be considered to satisfy the projection theorem, although this is far from obvious. In fact, because the CL signal depends on the mutual orientation of the electric field of the incident electron beam and the excited object, a rigorous treatment would require a full vector tomography reconstruction. However, the symmetry argument invoked by the researchers allows them to reduce the vectorial reconstruction problem to a scalar one. This simplification seems to be supported by a good agreement between the experiments and simulations.

The work of Atre and colleagues has the potential to contribute to the many fields in which imaging plasmonic modes is desirable. It is worth noting, however, that in the case of imaging plasmonic modes, the highest possible spatial resolution does not depend solely on the experimental set-up

(SEM plus CL). For example, plasmons exhibit non-local effects that may outweigh the probe size; in addition, the dimensions of the examined object and the spatial delocalization of the low-energy excitations should also be considered. the incident electron beam broadens as it goes through the sample, an effect that can be reduced by increasing the energy of the electron beam.

One of the most attractive features of Atre and co-workers' achievement is the fact that the experimental set-up is rather simple, consisting of an SEM with a far-field CL attachment. This should make the method accessible to many laboratories working in nanoplasmonics. To avoid artefacts, however, the symmetry argument should still be used with caution.

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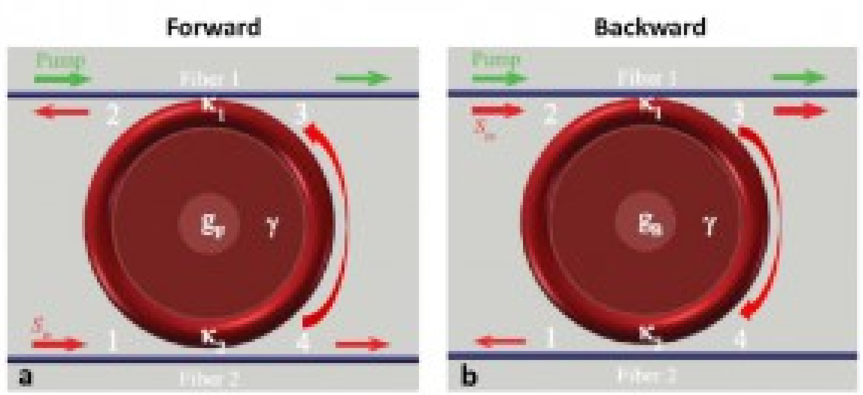
Modeling of On-Chip Optical Nonreciprocity with an Active

Microcavity

Jianming Wen et al., report the modeling of on-chip optical nonreciprocity with an active microcavity. On-chip nonreciprocal light transport holds a great impact on optical information processing and communications based upon integrated photonic devices. By harvesting gain-saturation nonlinearity, they recently demonstrated on-chip optical asymmetric transmission at telecommunication bands with superior nonreciprocal performances using only one active whispering-gallery-mode microtoroid resonator, beyond the commonly adopted magneto-optical (Faraday) effect. Here, detailed theoretical analysis is presented with respect to the reported scheme. Despite the fact that their model is simply the standard coupled-mode theory, it agrees well with the experiment and describes the essential one-way light transport in this nonreciprocal device. Further discussions, including the connection with the second law of thermodynamics and Fano resonance, are also briefly made in the end.



Reference:

Jianming Wen , Xiaoshun Jiang, Mengzhen Zhang , Liang Jiang , Shiyue Hua , Hongya Wu, Chao Yang and Min Xiao – *Photonics* 2015, *2*, 498-508; doi:10.3390/photonics2020498.

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