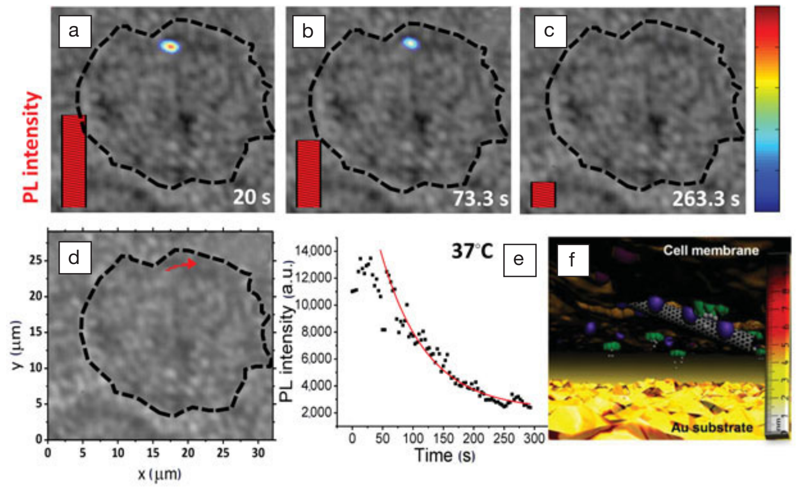
Nano Focus

Single nanotube endocytosis imaged in 3D using a plasmonic ruler

Carbon nanotubes (CNTs) exhibit unique optical and electrical properties. Profiting from this behavior, a group of researchers comprising G. Hong, J.Z. Wu, J.T. Robinson, H. Wang, B. Zang, and H. Dai from Stanford University has used the intrinsic ultrasensitive near-infrared (NIR) fluorescence enhancement property of CNTs to facilitate a unique three-dimensional (3D) method of imaging the cellular internalization of single molecules (i.e., endocytosis). These results were published in the February 28 issue of *Nature Communications* (DOI:10.1038/ncomms1698), and are based on the design of a "plasmonic ruler" comprising a single CNT near a plasmonic substrate made of gold islands (Au/Au film). The gold film exhibits a plasmonic resonance peak at a wavelength of ~800 nm and enhances the NIR fluorescence of the PEGylated CNT. The researchers also report an exponential decay in the fluorescence enhancement with distance of the PEGylated CNT from the plasmonic substrate. The addition of PEG helped prevent the CNT from being quenched by the metal substrate. This distance-dependent fluorescence enhancement was then used to create a working demonstration of a 3D tracking system with high temporal and sub-10 nm axial resolution.



Single nanotube imaging on cell membrane on a plasmonic gold substrate at 37°C. (a–c) Photoluminescence (PL) images of a single carbon nanotube (CNT) overlaid with optical images of a cell (outlined by the dashed line) at three time points: 20 s, 73.3 s, and 263.3 s after the incubation temperature stabilized at 37°C. (d) Two-dimensional trajectory of the single CNT moving on the cell membrane during endocytosis. (e) PL intensity (black squares) of this single nanotube plotted as a function of time and fitted to a first-order exponential decay. (f) Schematic of a single nanotube being endocytosed by the invagination of cell membrane and probed by the ultrasensitive "nanoscopic ruler" of the plasmonic Au substrate.

The researchers then employed their plasmonic ruler to track cellular internalization of individual single-walled CNTs. Trypsinized U87-MG cells were stained with highly diluted single-walled carbon nanotubes (SWCNTs) with cell targeting ligands at a low temperature. The stained cells were then cast onto the plasmonic gold substrate, and the plasmonically enhanced fluorescence of a SWCNT undergoing the process of endocytosis was imaged successfully by analyzing the near-infrared-II (1.1–1.7 μm wavelength, the so-called second window of near-infrared) emission spectra. Upon identification of a single CNT using the emission spectra, the incubation temperature was increased and stabilized at 37°C and the fluorescence of the SWCNT during endocytosis was tracked at 0.3 frames per second. The figure depicts an example of the SWNCT endocytosis imaging and tracking process on a plasmonic gold substrate. The resultant endocytosis of the SWCNT was found to be clathrin-dependent.

This 3D imaging system exhibits high temporal and axial resolution with the ability to track ~10 nm scale transmembrane displacements. However, in the current setup, the plasmonic enhancement property is limited to a distance of 20 nm from the gold substrate. The researchers predict that this limitation can be overcome by exploring different combinations of fluorophores and plasmonic substrates, which will lead to the creation of plasmonic rulers of varying lengths able to probe an extended range of nanoscale molecular motions.

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Nano Focus

Plasmonic gold nanotubes serve as sensitive refractive-index reporters when suspended in solution

Of the many potential applications of plasmonic metallic nanostructures, their use as refractive-index reporters has proven particularly successful. This behavior can be optimized when resonances occur in the near-infrared region, and through the use of hollow nanostructures, which experience reduced plasmonic damping and exhibit stronger surface plasmon resonance (SPR) signals than their solid counterparts. Many applications also demand that such structures can be homogeneously suspended in solution.

As reported in the March 27 issue of *Chemistry of Materials* (DOI: 10.1021/cm203184d; p. 963), C. Bridges, P. DiCarmine, and D. Seferos of the University of Toronto in Canada describe the first-known successful synthesis of solution-suspendable gold nanotubes.