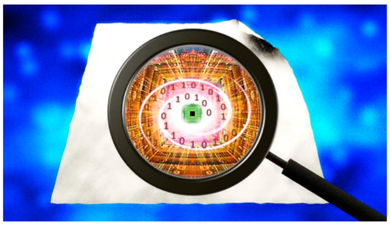
Thanks for the Paper Memories

Paper has a long and illustrious history in recording data. However, despite centuries of advances, paper remains a "write once, read many" device and is rapidly eclipsed by readable-writable electronic devices that can hold vastly larger amounts of data. Paper's properties, including its flexibility, low cost, and disposability, give it promise as a substrate for printed electronics to create circuits for data storage and other purposes. Thus, far, several types of electronic components have been printed on paper substrates, but researchers have yet to use paper as a medium for a memory device.

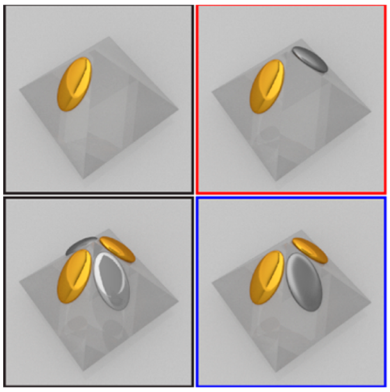
In a new study, Lien *et al.* (DOI: 10.1021/nn501231z) realize an all-printed electronic paper memory. The researchers created this paper-based memory device by screen-printing a paper substrate with carbon paste to serve as a bottom electrode, then applying a layer of TiO_2 nanoparticles with inkjet printing. They then printed silver nanoparticle ink dots as the top electrodes. Tests showed that the device, which uses resistive random access memory, performed well-defined memory-switching behaviors with a memory window that could easily be tuned by adjusting the insulator thickness. This device continued to perform well when bent and after being switched many times, and encoded data was easily disposed of through burning or shredding. On paper similar to a letter size, the researchers printed up to 1 MB of memory, with the potential of encoding up to 1 GB with a better printer. The authors suggest that paper memory could be used in medical biosensors, multifunctional devices, and self-powered systems.



Precisely Placing Nanoparticles for Hydrogen Sensing

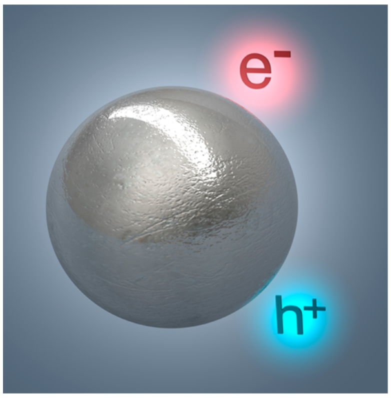
Metallic nanoparticles (NPs) can generate localized surface plasmons (LSPs) from spatially confined light. The LSP resonances of individual NPs depends on a variety of characteristics, including their composition, size, shape, and the local dielectric environment, as well as the proximity of other NPs. By placing NPs in dyads or assemblies of three or more, it is possible to manipulate their LSP resonance to change near-field and far-field characteristics compared to those of single NPs. Moreover, combining NPs of different materials into groups can deliver properties unachievable with single-composition assemblies. Although various bottom-up and top-down approaches can be used to create NP assemblies, they each have serious challenges, such as low throughput, the need for substantial purification processes, or limited assembly geometries.

In a new study, Yang *et al.* (DOI: 10.1021/nn502502r) detail a novel method for achieving independent control over the size, position, and material for up to four NPs within a subwavelength assembly. This lithographic method largely depends on using a Cr mask that can be removed and reconstructed between sequential depositions of different plasmonic NPs. Using this method, the researchers created monomer, dimer, trimer, and tetramer NP arrays. The researchers tested different configurations of Au–Pd heteroparticle assemblies, comparing their hydrogen gas-sensing capabilities. Results from simulations and experiments indicated that the Au–Pd nanoparticle dimers showed a red shift and trimers showed a blue shift with exposure to both low and high concentrations of hydrogen gas. The authors suggest that this method opens up a unique platform for optimizing plasmon-enhanced applications.



Hot New Theoretical Framework for Hot Carriers

Researchers have harnessed the ability of metallic nanostructures to produce collective electron oscillations, surface plasmons, for a variety of applications, including ultrasensitive biosensing, photothermal cancer therapy, drug delivery, and improved photovoltaic devices. These surface plasmons have finite lifetimes, with decay occurring either radiatively by emitting a photon, or nonradiatively by generating electron–hole pairs. Although using surface plasmon decay to generate hot carriers has been demonstrated repeatedly and is already being harnessed for applications, the physical processes responsible for this phenomenon are not yet well understood, hampering advances in this field.



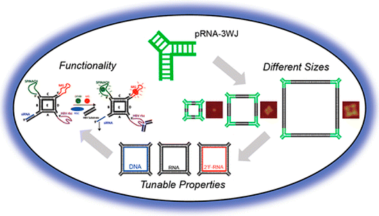
In a step forward, Manjavacas *et al.* (DOI: 10.1021/nn502445f) developed a simple theoretical model to describe the generation of plasmon-induced hot carriers in Ag nanoparticles and nanoshells. Considering nanoparticles with diameters ranging from 5 to 25 nm, this model describes the conduction electrons of the Ag as free particles in a finite spherical potential well. Consequently, the researchers calculated plasmon-induced hot carrier production using Fermi's golden rule. Their results show that including many-body interactions in the calculations had only a minor influence on carrier generation. The model's calculated rate of hot carrier generation mirrored the spectral profile determined by plasmon resonances. In addition, the model revealed that the particle size and hot carrier lifetime strongly influenced the hot carrier production rate and energies, with larger sizes and shorter lifetimes resulting in higher production rates but smaller energies and *vice versa*. The authors suggest that this model contributes to better understanding of the plasmon-induced hot carrier generation process and will eventually enable better design and optimization of devices that exploit this phenomenon.

10.1021/nn5045678

Tunable RNA Nanoparticles, Squared Away

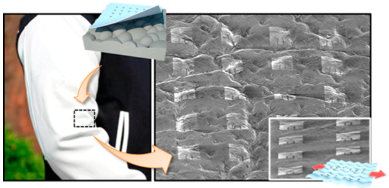
In the past several years, researchers have exploited the unique qualities of nucleic acids to build highly ordered nanostructures. Natural RNA forms a variety of complex structures with distinct motifs and modular units, which can be extracted and used to create artificial self-assembling RNA nanoarchitectures with the potential for applications in a variety of fields, including medicine. However, while size, shape, and physicochemical properties play an important role in delivery efficacy, biodistribution, and circulation time of nanoparticles, being able to tune these qualities in RNA and other nanoparticles has been challenging.

In a new study, Jasinski *et al.* (DOI: 10.1021/nn502160s) build on previous work manipulating the packaging RNA (pRNA) of bacteriophage phi29's DNA packaging motor to create square-shaped RNA architectures with tunable size, stability, and functionality. The researchers created squares using a single long strand of RNA and four shorter strands with pRNA three-way junction (pRNA-3WJ) motifs at each corner and four "arms" that extended from each corner. By modifying the lengths of these strands, they made three different sizes of squares, with side lengths ranging from about 4 to about 25 nm. Replacing the long strand with 2′F—C/U-modified RNA made the squares more resistant to degradation in fetal bovine serum and increased their melting temperatures. The researchers were able to functionalize these square scaffolds by adding aptamers, ribozymes, and siRNA to the arms, each of which maintained its functionality after being incorporated. The authors suggest that these tunable qualities make these RNA nanosquares promising for engineering, pharmaceutical, and medical applications.



Stuck on You: Graphene-Based Conformal Devices

Devices designed to conform tightly to uneven surfaces are attracting increasing attention due to their numerous applications, particularly in healthcare monitoring and wearable electronics. Finding ways to overcome strain, which can seriously degrade device performance, is one of the biggest challenges in designing these devices. Thus far, researchers have pursued several approaches toward addressing this difficulty, including employing elastic or bendable conductive materials or connecting rigid conductors with flexible bridges. However, these accommodations either limit performance or restrict use to applications with simple curvatures. Another design that combined filamentary serpentine metal mesh with an ultrathin silicon membrane offers significant promise but still limits flexibility due to the device's thickness of several hundred nanometers.



Seeking a better design, Park *et al.* (DOI: 10.1021/nn503446f) developed ultrathin conformal and stretchable devices, including a transistor and tactile sensor, using graphene as the active layer and a polymer film that acts as both the gate dielectric and a supporting layer. With the ability to scale thickness down to a combined 70 nm, the researchers show that these devices display a bending stiffness significantly lower than any previously reported for this type of device. Using animal hide as a model substrate, tests show that the devices adhere through van der Waals forces, eliminating the need for adhesive, and exhibit stable electrical characteristics even with repetitive bending and twisting. The authors suggest that this design holds promise for applications including fitness trackers and smart medical devices.

Toward Wearable Integrated Circuits

To operate successfully, flexible electronics need to display uniform electrical properties over a wide range of strain conditions, which presents a fundamental obstacle to developing complex integrated circuits (ICs) such as wireless communications. A central focus in creating these complex devices has been to design flexible low-noise amplifiers and frequency mixers. To that end, researchers have pursued various approaches using materials such as conventional silicon, III—V, and even organic semiconductors. However, these ICs could not operate at gigahertz frequencies at strains greater than 0.5%. Using graphene, investigators have recently developed flexible radio frequency (RF) field-effect transistors (FETs) with both cutoff frequencies and maximum oscillation frequencies above a few GHz under strains up to 1.75%. However, that device's performance still fell far short of an ideal graphene FET on a rigid substrate. The major challenge toward improving performance is overcoming high parasitic resistance.

In a new study, Yeh *et al.* (DOI: 10.1021/nn5036087) developed flexible, high-performance RF FETs using graphene as the channel material and a T-shaped aluminum top gate covered with a layer of naturally formed oxide, a design that enabled a significant reduction of the charged trap states at the gate/channel interface and the parasitic resistance at the source/drain contacts. Tests showed that this device yielded an extrinsic cutoff frequency of 32 GHz and a maximum oscillation frequency of 20 GHz. Both frequencies declined only slightly when the FET was subjected to strains up to 2.5%. The authors suggest that these results pave the way for the use of graphene in flexible, wireless communications.