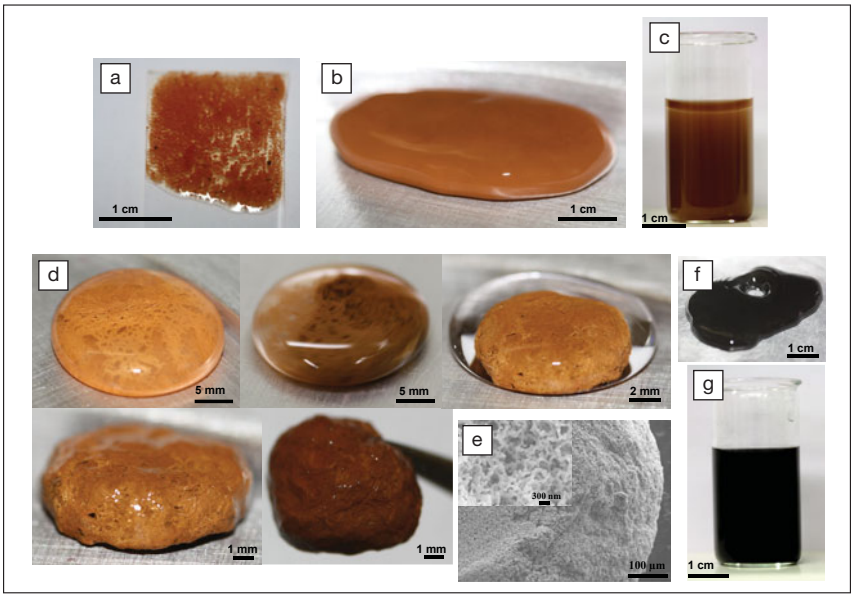
Leidenfrost drops prove to be versatile nanoreactors

The Leidenfrost effect, first investigated over 250 years ago, is well known as the phenomenon that causes water droplets to hover over the surface of a hot frying pan for several seconds while evaporating. This common phenomenon, which creates droplets in a super-heated state, has now been exploited to fabricate a wide range of nanoscale materials. As described in an article published in *Nature Communications* in October (DOI:10.1038/ncomms3400), researchers from several German research institutions investigated the physical properties of Leidenfrost drops in detail and established that overheating, thermal gradients, and electrical charge separation which occur within the Leindenfrost drops create an ideal environment to promote nucleation of functional nanomaterials.

Gold nanoparticles of 4 nm size were synthesized in a 2-mL drop of dilute $HAuCl_4$; however, when the OH^- concentration within the drop was increased by adding NaOH to the reaction solution, macroscopic, spongy three-dimensional (3D) metal nanostructures were formed. Nanoparticle synthesis, clustering, assembly, and fusion all occur within the levitating Leidenfrost drop (see Figure), and preliminary follow-up investigations show that the morphology, shape, and porosity of the resulting nanoporous metal can be controlled by varying the NaOH concentration.



Synthesis of nanoporous gold: (a) photograph of macroscopic spongy gold structure prepared by the Leidenfrost drop synthesis method collected on a glass substrate; (b) Leidenfrost pool of suspended nanoporous brown gold levitating on a hot plate and (c) the same solution inside a glass container; (d) time evolution for synthesis of solid nanoporous gold sphere from initialization to final product as a sponge; (e) scanning electron microscope (SEM) image of the spongy brown gold (inset: higher magnification SEM image); (f) Leidenfrost pool of suspended nanoporous black gold levitating on a hot plate and (g) the same solution inside a glass container.

Alternatively, homogeneous nanostructured coatings can be applied to different substrates *in situ* after the synthesis of nanostructures within the Leidenfrost reactor. To accomplish a uniform coating the substrate is placed inside the drop, which is rotated during the levitation phase. The team led by Mady Elbahri, who holds a joint appointment at the University of Kiel and the Helmholtz-Zentrum Geesthacht, demonstrated that Leidenfrost drops can even be used as nanoreactors to synthesize functional metal–polymer hybrid foams. Such a 3D coating of a complex structure cannot be obtained by conventional immersion synthesis techniques; it requires the unique aspects of a Leidenfrost nanoreactor.

"We understand the chemistry; extending the range of applications for Leidenfrost drop chemistry now necessitates a better understanding of the levitation process. This is the challenge we are working on," said Elbahri. For now, however, the limiting factors to advancing this new type of charge-driven chemistry are the size of the levitated droplet and its stability.

Birgit Schwenzer

Nano Focus

Origin of nickelate stripe phase uncovered

Strongly correlated materials often show unusual magnetic and electronic properties, such as high-temperature superconductivity. An example of such behavior is the formation of self-organized electronically ordered phases, which can cause charges to segregate into atomic-scale patterns and is linked to the emergence of high-temperature superconductivity.

An international research team has now illuminated the origins of the so-called "stripe phase" in which electrons become concentrated in stripes throughout a material.

"We're trying to understand nanoscale order and how that determines materials properties such as superconductivity," said Robert Kaindl, a physicist at Lawrence Berkeley National Laboratory (Berkeley Lab). "Using ultrafast optical techniques, we are able to observe how charge stripes start to form on a time scale of hundreds of femtoseconds."

Kaindl, W.-S. Lee (SLAC National Accelerator Laboratory), T. Sasagawa (Tokyo Institute of Technology), and their colleagues reported the results of

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their work with strontium-doped lanthanum nickelate (LSNO) in the October 24 issue of *Nature Communications* (DOI: 10.1038/ncomms3643).

Lead author Giacomo Coslovich, a postdoctoral researcher at Berkeley Lab, said, "We chose to work with LSNO because it has essential similarities to the cuprates (an important class of high-temperature superconductors), but its lack of superconductivity lets us focus on understanding the stripe phase alone."

In this LSNO crystal, stripes form only at cryogenic temperatures of about –168°C, yet at far higher temperatures, the team hit upon large changes in the material's infrared reflectivity. These invisible "color" changes represent an energy threshold for electrical currents, dubbed the energetic "pseudogap," which grows as the crystal cools, revealing progressive localization of charges around the nickel atoms.

The scientists then examined the dynamics of LSNO in pump-probe experiments, where they melted stripes with an initial ultrafast pulse of laser light and measured the optical changes with a second, delayed pulse. This allowed them to map out the early steps of charge ordering, exposing surprisingly fast localization dynamics preceding the development of organized stripe patterns. A final twist came when they probed the vibrations between nickel and oxygen atoms, uncovering a strong coupling to the localized electrons with synchronous dynamics.

Beyond the ultrafast measurements, the team also studied x-ray scattering and the infrared reflectance of the material to develop a thorough, cohesive understanding of the stripe phase and why it forms.

Having illuminated the origins of the stripe phase in LSNO, the researchers expect their results to provide new impetus to understand the pseudogap in other correlated oxides—especially in high-temperature superconductors where fluctuating stripes occur while their role in the superconductivity mechanism remains unclear.

Alison Hatt

Bio Focus

Bacteria construct tiny flagella "nanomachines" outside the cell

Researchers at the University of Cambridge have uncovered the mechanism by which bacteria build their surface propellers (flagella). The results, published in the November 10, 2013 online edition of *Nature* (DOI:10.1038/nature12682), demonstrate how the mechanism is powered by the subunits of the flagella themselves as they link in a chain that is pulled to the flagellum tip.

Previously, scientists thought that the building blocks for flagella were either pushed or diffused from the flagellum base through a central channel in the structure to assemble at the flagellum tip, which is located far outside the cell. However, these theories are incompatible with recent research that shows that flagella grow at a constant rate. The unexpected chain mechanism, in which subunits linked in a chain pull themselves through the flagellum, transforms current understanding of how flagellum assembly is energized.

The research team, led by Gillian Fraser and Colin Hughes, found that as each flagellum "nanomachine" is assembled, thousands of subunit building blocks are made in the cell and are then unfolded and exported across the cell membrane. Like other processes inside cells, this initial export phase consumes chemical energy. However, when subunits pass out of the cell into the narrow channel at the center of the growing flagellum, there is no conventional energy source and they must somehow find the energy to reach the tip.

The research team has shown that, at the base of the flagellum, subunits connect by head-to-tail linkage into a long chain. The chain is pulled through the entire length of the flagellum channel by the entropic force of the unfolded subunits themselves. This produces tension in the subunit chain, which increases as each subunit refolds and incorporates into the tip of the growing structure. This pulling force automatically adjusts with increasing flagellum length, providing a constant rate of subunit delivery to the assembly site at the tip.

Co-researcher Eugene Terentjev, of the Cavendish Laboratory, said, "Understanding how polymers move through channels is a fundamental physical problem. Gaining insight into this [research on bacteria] has potential applications in other disciplines, for instance in nanotechnology, specifically the building of new nanomaterials."

Nano Focus

Slowly cooled DNA transforms disordered nanoparticles into orderly crystal

"Single crystals are the backbone of many things we rely on—diamonds for beauty as well as industrial applications, sapphires for lasers, and silicon for electronics," said nanoscientist Chad A. Mirkin of Northwestern University. "The precise placement of atoms within a well-defined lattice defines these high-quality crystals." Now Mirkin's research group has built near-perfect single crystals out of nanoparticles and DNA, suggesting that DNA hybridization can drive the assembly of nanoparticles by a similar route to the traditional crystallization of atomic species.

His research group developed the "recipe" for using nanomaterials as atoms, DNA as bonds, and a little heat to form tiny crystals. This single-crystal recipe builds on superlattice techniques that Mirkin's laboratory has been developing for nearly two decades.

In this recent work, reported in the November 27 online edition of *Nature* (DOI:10.1038/nature12739), Mirkin, an

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