molecule sensing in nanogaps and the field enhancements observed in surface-enhanced Raman scattering and higher harmonic generation. But for now Maxwell's theory is still perfectly valid for most practical devices, at least until the accuracy of nanofabrication techniques moves from the nanometre to the ångström scale. ❐

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References
1. Savage, K. *et al. Nature* **491,** 574–577 (2012).
2. Berndt, R., Gimzewski, J. K. & Johansson, P. *Phys. Rev. Lett.* **67,** 3796–3799 (1991).
3. Kinkhabwala, A. *et al. Nature Photon.* **3,** 654–657 (2009).
4. Romero, I., Aizpurua, J., Bryant, G. W. & García de Abajo, F. J. *Opt. Express* **14,** 9988 (2006).
5. Duan, H., Fernández-Domínguez, A. I., Bosman, M., Maier, S. A. & Yang, J. K. W. *Nano Lett.* **12,** 1683–1689 (2012).
6. Ciracì, C. *et al. Science* **337,** 1072–1074 (2012).
7. David, C. & García de Abajo, F. J. *J. Phys. Chem. C* **115,** 19470–19475 (2011).
8. Kern, J. *et al. Nano Lett.* **12,** 5504–5509 (2012).
9. Zuloaga, J., Prodan, E. & Nordlander, P. *Nano Lett.* **9,** 887–891 (2009).
10. Esteban, R., Borisov, A. G., Nordlander, P. & Aizpurua, J. *Nature Commun.* **3,** 825 (2012).

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BIOCOMPOSITES

# Cells made of silica

Treatment of mammalian cells with dilute silicic acid followed by heating forms silica replicas of the cell template, offering a way to preserve cell specimens and generate biocomposites for various applications.

Jackie Y. Ying

Some living organisms are capable of producing minerals that serve different functions. For example, certain magnetotactic bacteria produce iron oxides that act as magnetic sensors. Silica-condensing microorganisms such as diatoms mineralize their tissues to form complex, functional architectures that span various length scales[1]. These well-controlled structures have inspired scientists to create similar inorganic materials. Previously, it was shown that microfabricated protein hydrogels could act as a template for creating stable biocomposites of silica. The locally crowded three-dimensional molecular environment associated with the high concentration of proteins in the confined volume of the hydrogels was thought to be important in the capture and concentration of the silica precursors[2]. Now, writing in the *Proceedings of the National Academy of Sciences USA*, Bryan Kaehr and colleagues[3] at Sandia National Laboratories, the University of New Mexico and the Center for Integrated Nanotechnologies show that naturally crowded molecular environments such as the packed biomolecular components within cells can also direct silica condensation.

Kaehr and co-workers immersed fixed or suspended mammalian cells in dilute silicic acid solutions at pH 3 for 16 h. Drying and heat treating at 550 °C removed the organic cellular components, leaving behind a silica replica that captured the dimensions and structural complexity of the cell templates, including their internal features (Fig. 1). Replicas created from suspensions of different types of cells showed different surface morphologies. Features of the cell membranes, such as membrane ruffles, filaments, blebs, clusters and smooth surfaces, were all replicated with high fidelity. Furthermore, sectioning of the replicas revealed that intracellular structures, such as the nuclear membrane with ring-like nuclear pore complexes, were also preserved.

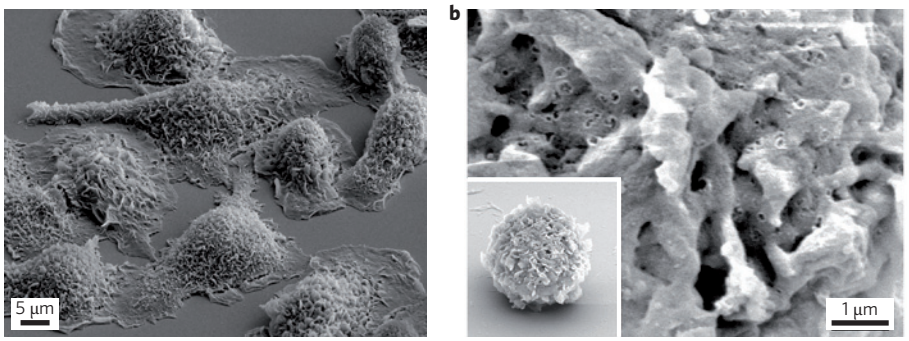


**Figure 1 |** Silica replica and cell–silica composite of mammalian cells. **a**,**b**, Scanning electron micrographs showing a silica replica of fixed cells (**a**), and a cell–silica composite of suspended cells (**b**). Both fixed and suspended cells are first treated with dilute silicic acid to obtain cell–silica composites. Heat treatment of these composites lead to the formation of silica replicas. Inset in **b** shows a cell–silica composite particle (~12 µm diameter) obtained without heat treatment. Figure reproduced with permission from ref. 3, © 2012 NAS.

Because silicification formed a continuous three-dimensional network that stabilized the cellular architecture, the porous silica replicas were mechanically robust; they could withstand the capillary forces during drying and the stresses during heat treatment with minimal shrinkage. The method is simple and does not require tedious dehydration steps or specialized equipment, making it a useful alternative to the conventional way of preserving cell specimens.

Staining experiments revealed that silica was present throughout the cytoplasm and nucleus of the cell. The key to the controlled silica deposition on the cell structures was to create a stable sol of monomeric or small oligomeric silicic acid species that would not undergo rapid condensation to form a separate silica gel via homopolymerization. By establishing a relatively stable sol at pH 3, the silicic acid species could gradually infiltrate all the subcellular structures and organelles (with the exception of large fluid-filled vacuoles), and avoid gel formation. Kaehr and co-workers[3] suggest that silica deposition at a pH of 3 involved the non-covalent interaction between weakly charged silicic acid species and the crowded biomolecular components, such as proteins, within the cells. The functional groups found on proteins in the cells are thought to promote acid- or base-catalysed condensation of the silicic acid species. This synthetic production of biocomposites based

on the slow kinetics of silica polymerization adds to the structural diversity currently available from the natural biomineralizing microorganisms.

Another interesting aspect of the silica replica of the cell is that when amphiphilic lipid bilayers in the form of liposomes were added to the replicas, they localized only on the outer surfaces of the replicas, suggesting that the membrane lipids could potentially be reconstituted. Furthermore, when treated with high-temperature pyrolysis (900 °C in nitrogen) followed by dissolution of the silica with basic solutions, the replicas were converted to carbonized systems. These porous carbon replicas, which possessed greater conductivity than the silica ones, could potentially be used as absorbents or in sensing applications[3].

Both the silica and carbon replicas of mammalian cells add to the diversity of porous materials that have been created through the use of organic templates such as surfactants[4], short-chain molecules[5] and block copolymers[6]. For example, silica[7], alumina[8] and transition metal oxides[9] with well-defined porosities (in the range of ~1–50 nm) have been derived after the removal of the self-assembled organic templates. These materials are of great interest as catalysts and advanced functional materials.

In the future, the use of the silica replicas of the mammalian cells to create biomaterials for cell culture and tissue engineering applications could be possible. For example, the replica can act as a mould for the polymerization of different types of biomaterials. Following the removal of silica (for example, by etching in a basic solution), a porous biomaterial that is an inverted copy of the silica replica can be obtained. The unique microstructure of the inverted copy and the surface chemistry of the biomaterial may facilitate the expansion of stem cells and primary cells. They may also induce the selective differentiation of stem cells towards the desired cell type when the inverted biomaterial replica of the desired cells is employed as a cell-culture substrate.

Furthermore, it would be of interest to examine if the present approach with cells can be extended to obtain silica replicas of tissues, organoids and organs. Such replicas would present an interesting way of preserving complex specimens for biomedical research and bioengineering applications. In organ transplant research, there has been substantial interest in using decellurized organs as a host for seeding stem cells from patients[10]. The inverted biomaterial replicas of tissues, organoids and organs may potentially act as a structural support and offer an environment for controlled differentiation of stem cells. ❐

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## References

1. Fratzl, P. & Weiner, S. *Adv. Mater.* **22,** 4547–4550 (2010).
2. Khripin, C. Y., Pristinski, D., Dunphy, D. R., Brinker, C. J. & Kaehr, B. *ACS Nano* **5,** 1401–1409 (2011).
3. Kaehr, B. *et al. Proc. Natl Acad. Sci. USA* **109,** 17336–17341 (2012).
4. Huo, Q. S. *et al. Nature* **368,** 317–321 (1994).
5. Sun, T. & Ying, J. Y. *Nature* **389,** 704–706 (1997).
6. Zhao, D. *et al. Science* **279,** 548–552 (1998).
7. Kresge, C. T., Leonowicz, M. E., Roth, W. J., Vartuli, J. C. & Beck, J. S. *Nature* **359,** 710–712 (1992).
8. Tanev, P. T. & Pinnavaia, T. J. *Science* **267,** 865–867 (1995).
9. Antonelli, D. M. & Ying, J. Y. *Angew. Chem. Int. Ed. Engl.* **34,** 2014–2017 (1995).
10. Gilbert, T. W., Sellaro, T. L. & Badylak, S. F. *Biomaterials* **27,** 3675–3683 (2006).

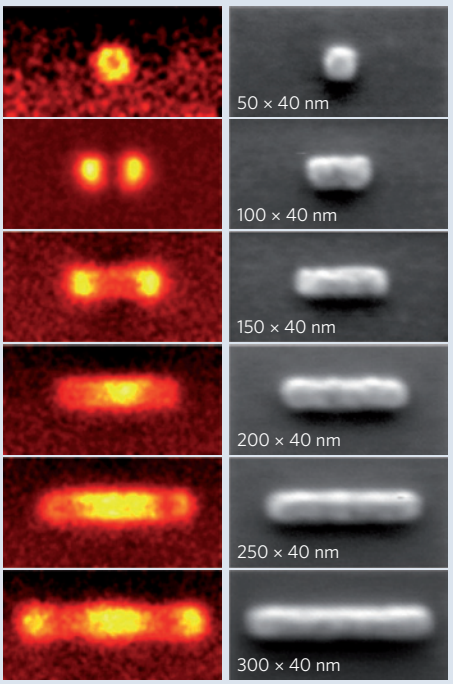
PLASMONICS

# The aluminium rush

An electromagnetic field may promote a concerted oscillation of electrons on a metal surface, allowing light to be concentrated in spaces that are smaller than its wavelength. To visualize these waves (or plasmonic modes), researchers use cathodoluminescence, where a highly focused electron beam excites the surface electrons, which then emit light on recombination.

In *Nano Letters* (http://doi.org/jrw; 2012), Naomi Halas at Rice University (USA) and co-workers report the plasmonic modes of an aluminium nanorod with spatial resolution of about 20 nm. The nanorod functions as an optical antenna concentrating light in specific regions. Transitions from circular emission (top row in the figure), where the modes from the longitudinal and transverse directions are degenerate, to dipolar and even quadrupolar emission, which arise from the longitudinal confinement, are clearly visible as the rod length increases. The modes remain intense throughout the investigated regions and can be tuned from the ultraviolet to the visible range by changing the nanorod length.

It is only recently that aluminium has been regarded as a serious contender for practical applications of plasmonics. Gold and silver have been the main players since the inception of the field because they allow long-distance propagation of plasmons with minimal loss of energy. However, for some applications propagation distance can be compromised, and the focus therefore shifted to the ability of nanorods to confine plasmons in tighter spaces. Here, aluminium outperforms both silver and gold. A particularly relevant application of this type involves the coupling between the semiconductor technology used in computers and the plasmonic modes of a nanorod. Aluminium is already compatible with fabrication technology for complementary metal-oxide semiconductors, and optimization of its optical properties at the nanoscale could lead to the integration of plasmonics and semiconductor electronics. Therefore, the spatially resolved characterization of the plasmonic properties of the aluminium nanoantenna reported by Halas and co-workers is an essential step in this direction. Add to the mix the fact that aluminium is the third most abundant element in the Earth's crust, and the potential for an aluminium rush in plasmonic science and technology is easily envisaged.



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