grew to become galaxies and galaxy clusters.

The early results from Planck demonstrate that the observatory is working flawlessly, and provide a first glimpse of its scientific potential. However, the best is yet to come. The main mission of Planck is to map the CMB radiation and its polarization with unprecedented precision. This measurement will provide a window onto the early Universe and offer clues as to what created the first seeds of structure. Planck may also detect the relic gravity waves from the Big Bang through the observations of CMB polarization. The task is complicated by the relative faintness of the CMB compared with other sources of radiation, such as dust emission, in most of the wavelength bands. Careful separation of components is thus needed to isolate the CMB signal, a task that has proved challenging and is the main reason that these early results do not include any primary CMB data. These CMB results are expected to be announced in early 2013. Given the spectacular instrument performance of Planck shown by its early findings[2,5,7], the cosmology community is eagerly awaiting more results. ■

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MATERIALS SCIENCE

Cell environments programmed with light

A combination of two light-induced reactions has been used to attach peptides to a polymeric gel, and then to detach them from it. This feat opens up opportunities for studying the effects of signalling molecules on cell behaviour *in vitro*.

MATTHIAS P. LUTOLF

The ability to use light to precisely control the activity of cells has transformed the way many experiments in biology are performed. In particular, optogenetic techniques — in which light is used to manipulate cells that have been genetically engineered to be light responsive — have revolutionized neuroscience by providing a completely new way to modulate cell signalling, even in live animals[1]. Writing in *Angewandte Chemie*, DeForest and Anseth[2] report that light can be used to dynamically manipulate not only the intrinsic cellular regulatory machinery, but also the external microenvironment of a cell. Specifically, they showcase a class of 'optobiomaterial' whose biochemical properties can be changed to influence cellular activity simply by having different sources of light shone on it.

Far from being intrinsically determined, cell behaviour such as proliferation, differentiation and migration are tightly regulated by spatio-temporally complex signals originating from the surrounding milieu (the extracellular matrix, ECM). For instance, the microenvironments (known as niches) surrounding rare adult stem cells in human tissues regulate stem-cell behaviour using a combination of local cell–cell interactions, ECM-derived signals and soluble signalling molecules. Together, these niche signals are crucial for ensuring lifelong maintenance of stem-cell function[3]. An understanding of how stem cells respond to signals from their extracellular environment is therefore essential, especially for realizing the therapeutic potential of stem cells.

Biologists have a variety of *in vitro* model systems at hand to study such complex cell–ECM interactions, and this enables them to uncover cell-signalling mechanisms in near-physiological, three-dimensional contexts. These models have been generated from crosslinked networks of protein components of the ECM such as collagen, or from ECM glycoproteins (polypeptides that have sugars attached) such as laminin. They have provided vital insight into extrinsic cell regulation, and in some cases have even made possible the formation of entire tissues from single stem cells *in vitro*[4]. Unfortunately, these biomatrices tend to suffer from uncontrollable batch-to-batch variability and are unable to modulate the availability of extrinsic signalling molecules — and thus cell function — controllably in space and time.

To recreate the dynamics of cellular microenvironments in three dimensions, researchers have sought strategies in materials chemistry that permit the biophysical and biochemical properties of matrices to be selectively modulated in a tailor-made fashion. Most approaches rely on well-characterized, crosslinked, synthetic polymers known as hydrogels that have ECM-like biophysical properties.

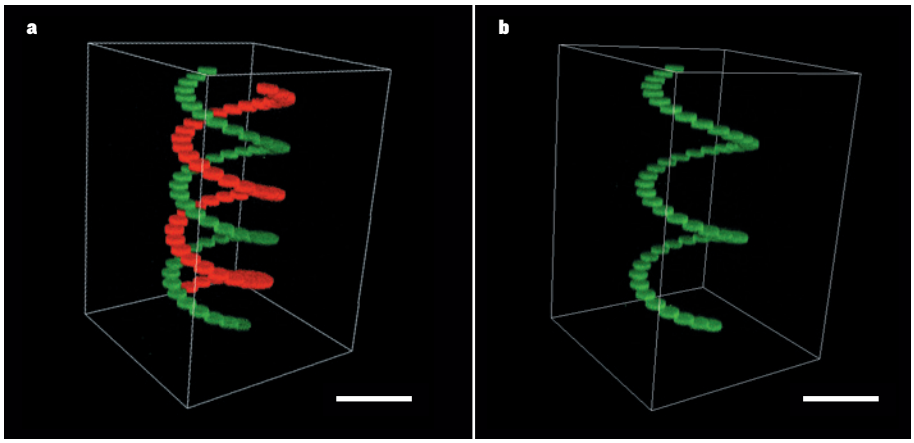

Figure 1 | Reversible gel patterning. DeForest and Anseth[2] have prepared hydrogels — water-absorbent polymeric networks — to which biologically active molecules can be attached and then removed using two light-induced reactions. By focusing light on specific regions of the gel, the authors precisely controlled the points of attachment. **a**, In this three-dimensional section of a hydrogel, fluorescently labelled peptides are bound in a double-helix pattern that was traced out using focused, visible laser light. False colour has been used to aid visualization. **b**, Subsequent irradiation of the red part of the helix with ultraviolet light has caused the peptides in that region to detach. Scale bars, 200 micrometres. (Images reproduced from ref. 2.)

But, in contrast to ECMs, most synthetic hydrogels are biologically inert because their polymer 'backbones' contain no biologically active components. This allows researchers to design very 'clean' experimental systems: biologically active molecules can be attached to hydrogels to perturb cell activity in a well-controlled fashion, without interference from the hydrogel itself.

Several research groups have carried out work in which light-sensitive molecular building blocks were attached to hydrogel networks to generate artificial ECMs in which the properties of microenvironments could be specifically modulated by light exposure[5]. For example, the introduction of chemical groups that can be cleaved by ultraviolet light has led to hydrogels that soften on light exposure[6]. Conversely, the incorporation of groups that form crosslinks between polymer chains when irradiated with ultraviolet light has resulted in materials that stiffen upon such irradiation[7].

Systems in which light triggers the coupling[8,9] or removal[6] of biologically active molecules to or from hydrogel polymer networks have also been devised. These light-mediated approaches to modifying hydrogels have been used to control some aspects of the basic three-dimensional behaviour of cells embedded in the materials, such as adhesion to the artificial ECM or migration. But because the modifications involved are irreversible, they allow only one-way manipulation of cell activity.

DeForest and Anseth's work[2] now demonstrates fully reversible modulation of biologically active building blocks within light-sensitive hydrogels. They synthesized small peptides that can act as signals for cell adhesion, to which a short linker section was attached. The free end of the linker was a chemical group that can react with alkene groups in a hydrogel when irradiated with visible light, thereby attaching the peptide to the gel (Fig. 1). Another part of the linker was a group that breaks apart when irradiated with ultraviolet light; by shining this light on a hydrogel that had been decorated with the peptides, the authors could detach the peptides from the gel.

Crucially, both light-activated reactions are cell-compatible, which allowed DeForest and Anseth to attach (or detach) the peptides to (or from) their hydrogel in the presence of mouse embryonic fibroblast cells. By controlling precisely when and where the cell-adhesive peptides bound in the gel, the authors could control the duration and locations in which the cells attached and spread.

In a first gel-patterning step, DeForest and Anseth used visible light to create small 'islands' of peptides to which fibroblasts grown in culture with the gel adhered. In a second step, conducted after one day of culture, the authors removed peptides from areas of the islands using ultraviolet light. This caused rapid, selective detachment of cells from those areas. The authors showed that the removed cells could then be grown again in culture, or analysed in other assays. As DeForest and Anseth suggest[2], this kind of protocol could be widely used to manipulate and study subsets of cells (or even individual cells) of larger cell populations.

One long-term goal of work such as this is the development of materials to act as scaffolds for tissue regeneration. Can we expect this and/or similar techniques to transform tissue engineering in the same way that optogenetics is transforming neuroscience? This is, of course, difficult to predict. For DeForest and Anseth's hydrogel to be fully physiologically relevant, the ability to attach and release full-length proteins[9] — rather than short peptides — to the material needs to be developed. And it remains to be seen whether their approach is directly translatable to tissue regeneration *in vivo*. Furthermore, it could be argued that these methods will be valuable for tissue regeneration in only a relatively few cases, such as those in which much simpler scaffolds fail, because the spatial arrangement of ECM signals is necessary for driving regeneration.

Nevertheless, the reversible, dynamic control of chemical and physical gel properties should allow previously impossible experiments to be performed in cell culture. For example, it might be used to investigate how individual stem cells differentiate or renew themselves in response to changes in signals from an artificial microenvironment that spatially resembles natural stem-cell niches. Alternatively, three-dimensional environments for stem cells could be made in which the display or release of molecular signals is graded, to mimic processes that occur during the embryonic development of an organism. DeForest and Anseth's optobiomaterials therefore represent a major contribution to a nascent field in stem-cell bioengineering. ■

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QUANTUM COMPUTING

A topological route to error correction

Quantum computing is plagued by noise and small errors. An approach based on topological techniques reduces the sensitivity to errors and boosts the prospects for building practical quantum computers. SEE ARTICLE P.489

JAMES D. FRANSON

Quantum computers have the potential to solve numerical problems that would be impossible on a classical computer. Roughly speaking, the superposition principle of quantum mechanics allows a quantum computer to perform many calculations simultaneously on a single processor, and entanglement (non-classical correlations) provides an exponential increase in its memory capacity. Unfortunately, the same properties that enhance the computational power of a quantum computer also make it sensitive to errors produced by interactions with the environment or by imperfect logic operations. In this issue, Yao *et al.*[1] (page 489) describe the first experimental demonstration of a technique that uses topological effects to reduce the sensitivity of a quantum computer to errors.

The bits in a quantum computer, commonly referred to as qubits, can be represented by a two-state quantum system, such as the two quantized energy levels of an atom (Fig. 1a). One state represents a logical value of '0' and the other state represents a '1' — meaning that, like a classical computer, a quantum computer is a digital device. But unlike classical physics, quantum mechanics allows situations in which both possibilities (0 or 1) exist simultaneously. The probability of finding the system in the 0 or 1 state is equal to the square of a complex number known as the probability amplitude. As a result, the information stored in a qubit corresponds to a continuous range of