Nanoscience and the Mobile Device

The Vision

Why has a video about nanotechnology received more than 2.3 million views on YouTube? The star of the show is called Morph, and its appeal is undeniable: a wearable device that changes shape, detects toxins on your food, draws power from the sun, and repels a drop of honey. Morph isn't a product you can buy tomorrow, but it isn't science fiction either. Nokia created the Morph video to illustrate a collective vision for the mobile device of the future—a vision that is driving Nokia's research efforts in nanoscience and nanotechnologies.

The Mobile Gateway

Think of Morph as a snapshot of a new kind of mobility, made possible by a personal device that intelligently bridges local and global information. By sensing ambient elements, physical objects, and your individual context, the device adapts its form factor and functionality accordingly. It connects automatically to global services and communities, transmitting local data and returning context-relevant information in real time.

Very compliant, very human, this tiny device is transparent to your daily activities. It conforms to the variety of your requirements—there's no need to deviate from your usual behavior. You're always on and always connected to a range of objects and services not yet imagined.

You Can't Get There from Here

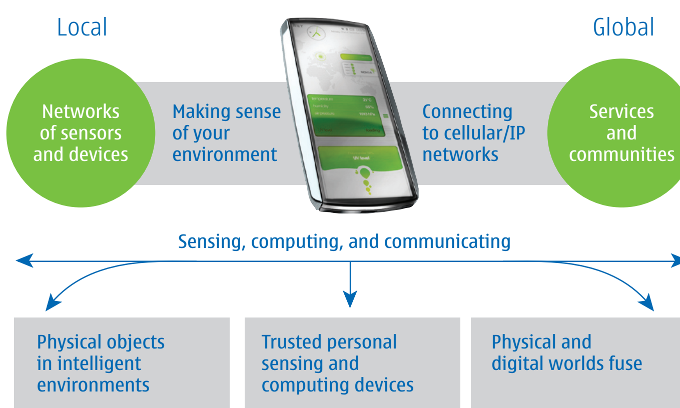
Combining so much capability with true mobility results in a list of steep demands. A self-configuring unit that can learn its context—and adapt instantly—presents severe challenges for sensor technologies. Vastly more efficient computing solutions are required to minimize power consumption. And new materials and fabrication methodologies are needed to produce a robust, self-healing device that can operate for days under rough conditions.

How can we surmount the barriers? We need new architectures and models for integrating cognitive and system components. We need to push far beyond current technologies and current ways of thinking about electronics design and material science. (Even Moore admits we're nearing the limits of his eponymous law.)

Enter nanoscience. "There's plenty of room at the bottom," Richard Feynman proposed in 1959, and that's exactly where Nokia is looking for breakthroughs. By engaging in deep, far-reaching research in nanotechnologies—and with the mobile gateway as the guiding vision—Nokia is working to discover surprising solutions for energy efficiency, learning and adaptivity, and durable structures and materials.

The mobile gateway

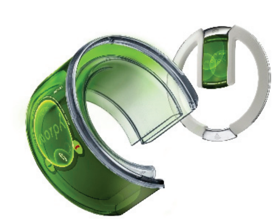
The mobile device works at the center of your everyday life, interconnecting local intelligence—temperature changes, air pollution, your heart rate—with needed information and services.



What's behind Morph?

When New York's Museum of Modern Art invited Nokia to participate in its exhibition "Design and the Elastic Mind," the answer was Morph. Morph featured in the exhibition catalog and on the MoMA website.

The Morph video demonstrates how advances in nanoscience might shape the future of mobility. In fact, all of the elements of Morph reflect real projects in Nokia labs. To view the video, go to YouTube and search "Nokia Morph."



The Work

In the ongoing race to make phones smaller, thinner, stronger, and increasingly functional, Nokia is already beginning to apply nanotechnologies. But to deliver a product like Morph is an entirely different story. How do we make sure the right work is happening?

Our challenge is to understand technologies today that will still make sense in 2015 or 2020—especially as new technologies lead to sometimes surprising applications. Given a lead time of 10 to 15 years for a solution like the mobile gateway device, our work is well under way. Following are examples of areas of investigation that may support Nokia's mobile gateway vision.

Sensors and Sensing Everywhere

Sensors integrated into future devices will construct a complete awareness of the user context—both personal and environmental—enabling an appropriate and intelligent response.

Nanoscale sensors

Nanotechnologies can be used to create new building blocks and materials that improve both the resolution and the stability of microsensors. This is in part because nanocomponents have an immense surface area–to-volume ratio, allowing plenty of space for chemical reactions.

Nanostructures can also enable robust chemical and biochemical sensing, especially in scenarios where nanoscale values are being measured. And since nanoscale is the scale of the fundamental processes of life, nanoscale chemical sensors can leverage principles and materials common to biological systems.

Nanowire lithography on silicon

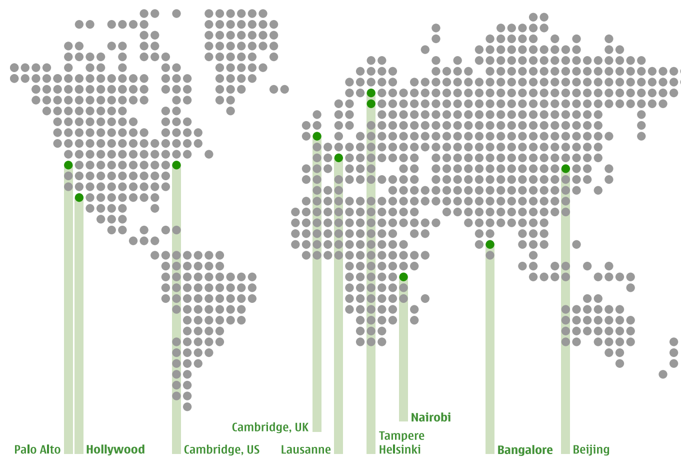
To improve sensor and signal processing characteristics, nanotechnology can yield innovative fabrication techniques that exploit the building-block nature of nanocomponents. Scientists at Nokia Research Center and the University of Cambridge have demonstrated a versatile new nanowire lithography (NWL) process for fabricating a range of ultrasmall, large-area, and self-aligned 3D architectures.

By applying chemically grown silicon nanowires as etch masks, the research team stenciled nanowalls into thin films of silicon (Si), producing interesting electronic transport effects. This same lithographic method can be applied to create patterned nanostructures of other materials besides Si, such as metals or graphene.

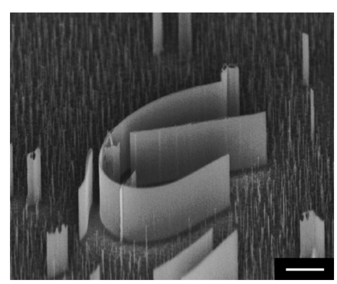
The applications of NWL also extend into the third dimension. Under proper conditions, a periodic undercutting can be obtained during etching, producing an array of vertically stacked nanowires from a single nanowire mask. Together, these and other Nokia projects highlight the potential of this NWL process for next-generation nanoelectronics, sensing, and electromechanical systems.

World-class collaboration network

Long-term scientific and commercial impact isn't produced in a vacuum. That's why Nokia collaborates with leading research centers in universities around the world, including Stanford, MIT, the University of Cambridge, and the Technical University of Helsinki/TKK. This culture of open innovation combines empirical research—hands-on work with basic materials—with goal-oriented industrial R&D that will result in game-changing technologies and products.

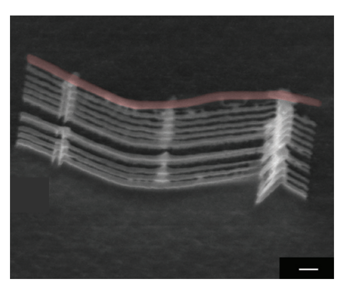


3D architectures using nanowire lithography



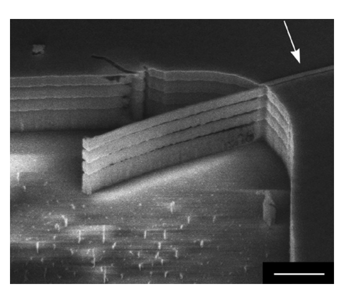
Scale bar = 2 micrometers

Scanning electron microscope (SEM) image of deep nanowalls fabricated using nanowire lithography. The nanowire masks were initially dispersed from solution, and two of them were randomly assembled to form the € (euro) symbol. The symbol was then carved into the Si wafer using deep reactive ion etching (DRIE).



Scale bar = 100 nanometers

Array of vertically stacked nanowires obtained via undercut from a single nanowire mask (pink). The height and separation of the nanowires within the array are controlled by the DRIE parameters.



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Aligned array of suspended silicon nanocantilevers obtained by clamping—before the etching process—one-half of the original nanowire mask with a protective pad (arrow).

Applications of Nanoscale Zinc Oxide

A wearable and distinctly easy-to-use device demands an extraordinary surface. Low-cost, environmentally friendly, and touch-sensitive, it should be so versatile that the entire surface of the device is available for user interface. As Nokia builds a library of novel surface features—such as toughness, dirt repellency, antenna integration, optical effects—zinc oxide (ZnO) nanowire arrays emerge as promising building blocks for functional surface structures.

Sensing surfaces using piezoelectric nanowire arrays

ZnO exhibits an unusual combination of properties, including uniaxial piezoelectric response and n-type semiconductor characteristics. Nokia is exploiting these qualities to achieve strain-based electromechanical transducers—ideal for touch-sensitive (even direction-sensitive) surfaces.

Arrays of ZnO nanowires can be fabricated at low temperatures (roughly 70–100˚C), providing compatibility with polymer substrates, such as polyethylene terephtalate (PET). By coating a substrate (silicon, glass, or PET) with an array of these ZnO nanowires, the electrical signals on the surface can be activated by mechanical force. Since ZnO nanowires and nanoparticles are nearly transparent, this technique can be used to develop compliant, touch-sensitive, active matrix arrays that sit on top of displays or other structural elements.

Harvesting solar energy for photovoltaics

ZnO nanostructures may also play an important role in low-cost photovoltaics. Researchers from Nokia and the University of Cambridge have demonstrated a new method for making a full solid-state, flexible dye-sensitized solar cell (DSSC). Although their efficiency needs improvement, these DSSCs may present a low-cost alternative to silicon-based photovoltaics. Because conventional DSSCs also pose challenges related to solvent leakage and evaporation, Nokia is working to develop a stable DSSC based on solid electrolytes.

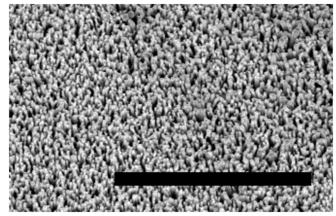
Nokia's team has produced a promising photocurrent using a novel ionic liquid gel, organic dye, and a thin film of CNTs stamped on a flexible PET substrate. The CNTs serve both as the charge collector and as scaffolds for the growth of ZnO nanoparticles, where the black dye molecules are anchored. The flexible and lightweight qualities of this film open up the possibility of a continuous roll-to-roll process for low-cost mass production of DSSCs.

The Innovation Ecosystem

As the integrator of the mobile gateway vision and the technologies that will enable its realization, Nokia operates within an extensive ecosystem of innovative companies and research institutions. Our engagement in both deep science and applied research enables us to understand the required architectures and components—and to identify technology development gaps and opportunities within the ecosystem.

Zinc oxide nanowire arrays

Nokia is working with the University of Cambridge, Department of Electrical Engineering, to develop ZnO nanowire arrays for touch-sensitive surfaces.



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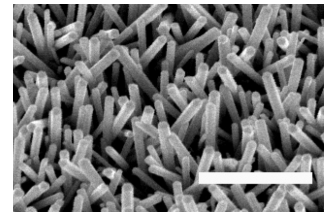

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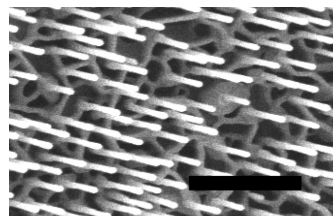

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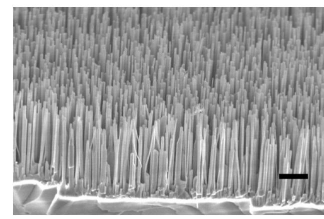

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In the Morph vision, the surface of the device—in fact, the entire device—is sensitive to both touch and movement.

Questions we are asking

As Nokia looks toward the mobile device of 2015 and beyond, our research teams, our partner academic institutions, and other industry innovators are finding answers to the following questions.

- ? What will be the form factors, functionalities, and interaction paradigms preferred by users in the future?
- ? How can the device sense the user's behavior, physiological state, physical context, and local environment?
- ? How can we integrate energy-efficient sensing, computing, actuation, and communication solutions?
- ? How can we create a library of reliable and durable surface materials that enable a multitude of functions?
- ? How can we develop efficient power solutions that are also lightweight and wearable?
- ? How can we manufacture functional electronics and optics that are transparent and compliant?
- ? How can we move the functionality and intelligence of the device closer to the physical user interface?
- ? As we pursue these questions, how can we assess—and mitigate—possible risks, so that we introduce new technologies in a globally responsible manner?

The Upshot

Even as nanoscience is changing what's possible in a mobile device, the advantages it yields—faster, cheaper, smaller, more robust, more powerful—will overhaul the role of the mobile device in our world. Most significant could be the integration of low-cost sensors and actuators that detect and translate contextual details, delivering meaningful benefits far beyond the value of the next cool gadget. Consider a few possibilities.

Physical and Digital Worlds Fuse

The vision of ambient intelligence describes a network of sensors connected to one or more computing devices. Sensors will be everywhere: in your pocket, in your faucet, in your refrigerator, at your front door, and in your running shoe. The device integrates data from your physical world, deduces patterns, identifies issues, consults with Internet services, and responds with intelligence—seeming to anticipate your every need—all at the rapid pace of your daily life.

Computational Medicine and the Individual

Start with inexpensive sensors that can be worn, implanted, or swallowed (as Feynman suggested in 1959). Marry them with data reduction capabilities that compute trends and interactions to build a holistic personal medical profile. Equipped with this information, the individual's mobile device can relay the diagnosis to health care resources, dispatching an ambulance automatically, for example, or generating a prescription delivered to the pharmacy over the Internet.

Connecting the Unconnected

In developing nations, we see more basic (and potentially crucial) applications. The mobile device's integrated sensors can monitor levels of pollutants, bacteria, and other environmental or health risks and notify officials when thresholds are exceeded. Also critical are point-of-care diagnostics and patient monitoring—empowering health care providers to deliver on-the-spot treatment, informed by global Internet services and medical data banks.

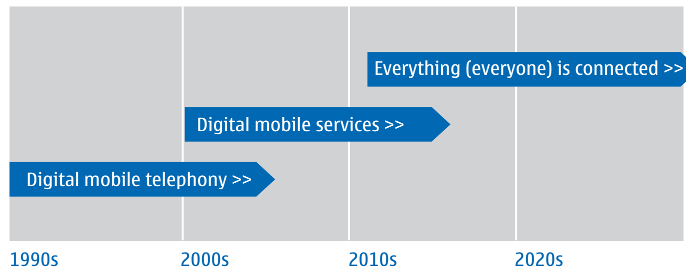
Nokia Technology Insights Series

This paper is provided by Nokia Research Center. Looking beyond Nokia's current business, Nokia Research Center engages in open collaboration with consumers and research universities alike, seeking to explore the creative collision between what is valuable and what is possible.

For more information about research efforts at Nokia–or to learn about opportunities to join our team–visit research.nokia.com.

The Internet of things

New mobile applications and services are creating new business dynamics, similar to the ongoing revolution of Internet business models. The focus shifts from the infrastructure to the user experience.



For further reading

Books

Introduction to Nanotechnology, Charles P. Poole & F.J. Owens

Understanding Nanotechnology, Scientific American

Nanoscale Science and Technology, Robert Kelsall, Ian Hamley & Mark Geoghegan

Nanotechnology: Science, Innovation, and Opportunity, Lynn E. Foster

Nanoelectronics and Information Technology, Rainer Waser (ed)

Nanochemistry, Geoffrey A Ozin & Andre C. Arsenault

Coming in 2009 from Cambridge University Press: *Nanotechnologies for Future Mobile Devices*, Olli Ikkala, Asta Kärkkäinen, Tapani Ryhänen, Mikko Uusitalo, Mark Welland (Eds.)

Websites

Cambridge Nanoscience Centre, University of Cambridge: www.nanoscience.cam.ac.uk

Foresight Nanotech Institute: www.foresight.org

Institute for Nanoelectronics and Computing (INaC): www.inac.purdue.edu

National Nanotechnology Initiative: www.nano.gov

Nature Nanotechnology: www.nature.com/nnano/index.html

PhysOrg.com—Nanotechnology: nanotech.physorg.com

Nokia Research Center—NanoSciences: research.nokia.com/projects/nanosciences

The Morph concept: www.nokia.com/A4852062

Richard P. Feynman's "Plenty of Room at the Bottom" speech: www.its.caltech.edu/~feynman/plenty.html

For more information about Nokia's work in nanoscience and for links to research papers, visit research.nokia.com/projects/nanoscience.

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