A conversation with Philip Moriarty on September 3, 2014

Participants

- Philip Moriarty – Professor of Physics, University of Nottingham
- Nick Beckstead – Research Analyst, Open Philanthropy Project; Research Fellow, Future of Humanity Institute, Oxford University

Note: This set of notes was compiled by GiveWell and gives an overview of the major points made by Prof. Moriarty.

Summary

GiveWell spoke with Philip Moriarty as part of an Open Philanthropy Project investigation of nanotechnology as a potential global catastrophic risk. Conversation topics included: the current state of atomically precise manufacturing (APM), the in-principle feasibility of APM, and timelines for development.

The current state of atomically precise manufacturing (APM)

Researchers are attempting to make progress in APM primarily through "hard" approaches (such as scanning probe microscopy (SPM)) and "soft" molecular self-assembly approaches. Prof. Moriarty works on SPM and is most enthusiastic about that approach.

Scanning probe microscopy (SPM)

Scanning probe microscopes fundamentally enable imaging and manipulation of atoms. However, the vast majority of work to date has been on translation (pushing/pulling/sliding) atoms and molecules across surfaces. There is very little work on combining atoms/molecules to form molecules, although two notable examples are the work of Wilson Ho's group and the Karl-Heinz Reider/Gerhard Meyer group back in 1999 and 2000 respectively.

SPM allows researchers to combine individual atoms, which are held at the tip of scanning probe microscopes, and surfaces. This technology represents the closest researchers have come to building nanoscale objects one atom at a time. Different types of tips are used to produce different reactions. For example, researchers have exchanged, under highly controlled vacuum conditions, a tin atom from the tin-coated tip of a scanning probe microscope with a silicon atom from a silicon surface. IBM used scanning tunneling microscopy (a form of SPM) to print a nanoscale image of its logo.

Molecular self-assembly

In molecular self-assembly, such as DNA nanotechnology, molecules form into a desired arrangement without management from an outside source. Researchers focusing on this approach are also striving to understand how to establish chemical bonds between atoms in a well-defined and defect-free pattern. In this context, long-range order is much less straightforward than local order.

Multiple self-assembly process can occur in parallel, making it a potentially faster assembly process than SPM. Self-assembly has the added challenge, however, of requiring atoms to be weakly bound at first (so they can slide past each other into place) and strongly bound later on (so the finished product can be strong). Researchers are attempting to discover how to address these two conflicting needs.

Scalability is also a major challenge for this approach. Currently, we have very little sense of how to go from building 20 nm structures to 1 mm structures.

Obstacles to progress

Researchers are currently working on these bond-formation challenges in two dimensions. Advanced APM would necessitate precise control of these bonds in three dimensions. No one has built a 3D object at the nanoscale an atom at a time with the trajectory of every atom controlled, as Drexler described in *Nanosystems*. In order to do this with SPM, researchers need to know more about, and be able to control and recover, the chemical environment at the end of the microscope tip.

Major ongoing obstacles to progress in APM include:

- Building larger objects
- Producing large quantities of output quickly
- Correcting errors that occur during the manufacturing process
- Visualizing what is being built
- Mastering the chemistry of surfaces

Prof. Moriarty believes advanced APM is unlikely to be achieved until relatively far in the future because it requires many difficult technologies and has advanced slowly up to the present, and that other scientists working with SPM have similar views. He is extremely skeptical of claims by, e.g., Ray Kurzweil, that advanced forms of atomically precise manufacturing will be available in the 2030s. Speaking optimistically, non-scalable atom-by-atom construction of small 3D objects (i.e. nanoparticles) using SPM techniques might be possible in about 30 years. Advanced APM is extremely unlikely to be possible before then.

In-principle feasibility

APM is probably feasible for a relatively narrow subset of materials, in principle, but there will be very substantial engineering challenges. It may be more likely to work with some materials rather than others. For example, silicon materials seem more promising than diamondoid materials due to the greater ease of preparing large atomically flat regions of low defect density silicon surfaces.

Risks

We are very distant from creating general-purpose, programmable nanofactories capable of quickly building macroscopic structures. Any risks such technology might pose are very distant at the present. It would probably be hard to find people in the nanoscience community who take such risks seriously.

The nanoscience community's reception of APM

It is hard to find people in the nanoscience community who have significant familiarity with Drexler's work, though there are some. No very comprehensive summary of criticism of his work has been formally published. However, there is a great deal of technical criticism at Richard Jones' Soft Machines blog, including the ~ 50 page debate Prof. Moriarty had with Chris Phoenix almost ten years ago. In the last ten years, the state of the debate has not significantly changed.

People to talk to

- Richard Jones, Professor of Physics, University of Sheffield
- Mervyn Miles, Professor of Physics, University of Bristol
- Erik Winfree, Professor of Computer Science, California Institute of Technology
- Leonhard Grill, Professor of Physical Chemistry, Fritz-Haber Institute
- Oscar Custance, Senior Scientist, National Institute for Materials Science
- Kazuomi Sugamoto, Professor, Orthopedic Biomaterial Science Laboratory, Osaka University
- Yasuhiro Sugawara, Professor of Engineering, Osaka University
- Peter Beton, Professor of Physics, University of Nottingham
- Neil Champness, Professor of Chemical Nanoscience, University of Nottingham
- Mike Crommie, Professor of Physics, UC Berkeley
- Leo Gross, Research Staff, IBM Research
- John Randall, Zyvex Labs

References

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All GiveWell conversations are available at http://www.givewell.org/conversations