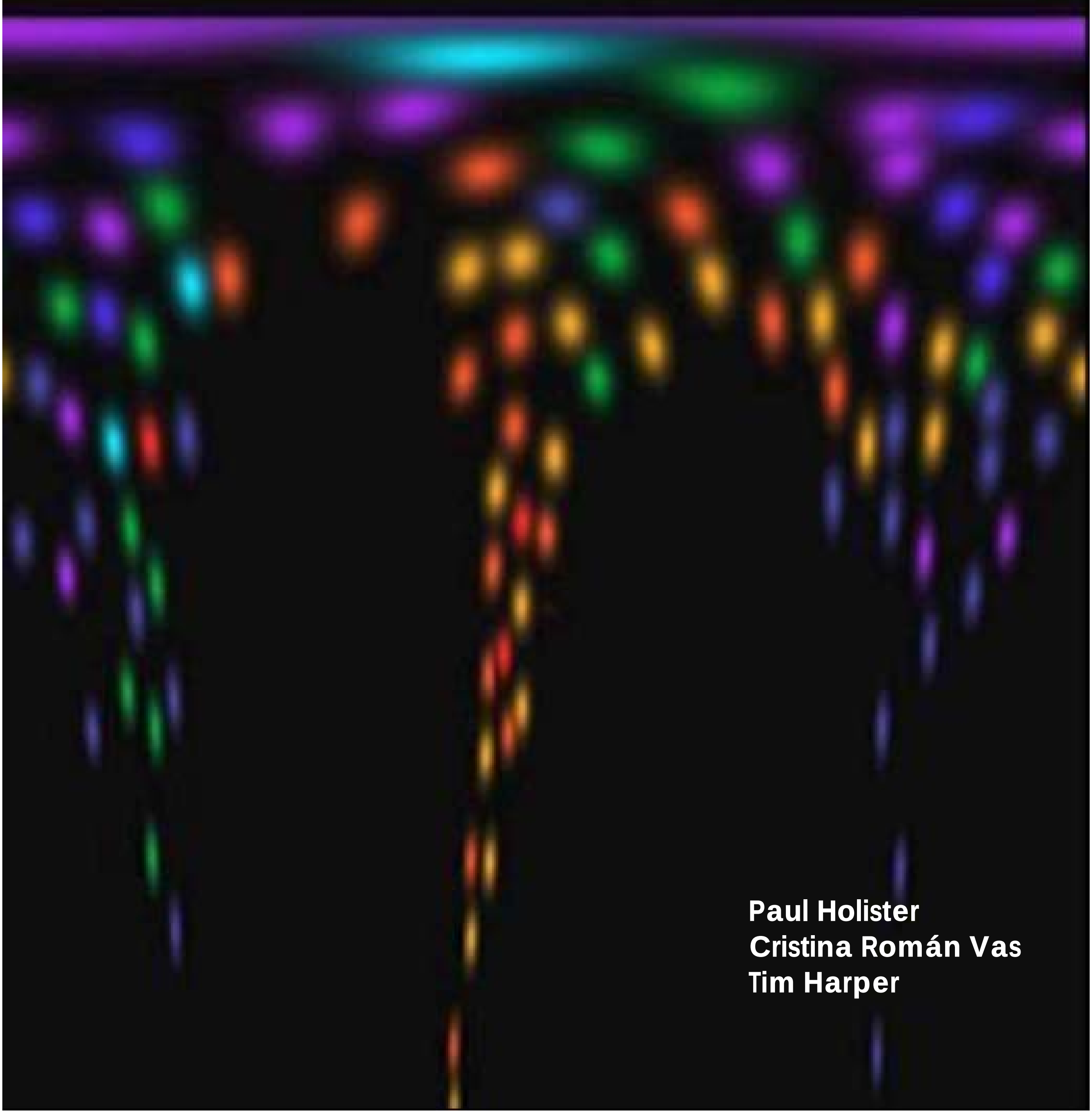
Molecular Electronics

Technology White Papers
nr. 9



Paul Holister
Cristina Román Vas
Tim Harper

MOLECULAR ELECTRONICS

Technology White Papers nr. 9

Release Date: October 2003

Published by Científica

Científica, Ltd.
www.cientifica.com

Científica is the world's largest nanotechnology information company. With a global network of partners, the company organizes both scientific and business conferences and provides information and research to thousands of clients worldwide. Científica is the publisher of the Nanotechnology Opportunity Report and TNT Weekly.

Authors

Paul Holister
Cristina Román
Tim Harper

Disclaimer

1. Accuracy of Information.

The information contained in this report has been obtained from sources believed to be reliable. Científica disclaims all warranties as to the accuracy, completeness, or adequacy of such information. The reader assumes sole responsibility for any loss or damage resulting from investment and/or business decisions based on the contents of this report.

2. Views of the authors.

The information contained in this report represents the views of Científica. Científica is solely responsible for the content of this report.

3. Limitation of Liability.

In no event will Científica or any co-author be liable for:

(i) damages of any kind, including without limitation, direct, incidental or consequential damages (including, but not limited to, damages for lost profits) arising out of the use of information contained in this report or any information provided in this report.

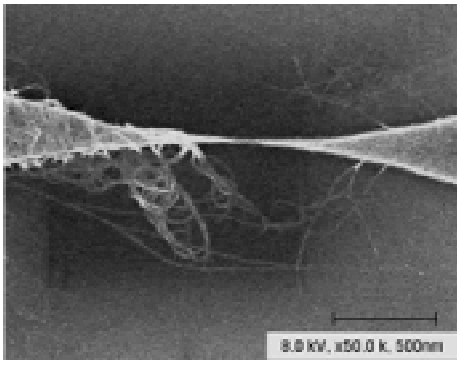
(ii) any claim attributable to errors, omissions, or other inaccuracies in this report or interpretations thereof.

Origin of content

The free reports in this series are extracted from the technology reports that make up the Nanotechnology Opportunity Report collection and are designed to offer an introduction to the variety of technologies that fall under the nanotechnology umbrella. The full reports also include 'opportunities' sections, covering the various applications of the technology and their effects on markets, and a list describing the companies involved in the technology.

Molecular electronics

Introduction to molecular electronics



Particle sensor formed with a broken nanotube. Courtesy of Mechanical Engineering department. Northwestern University.

There are at least three very different ways in which molecules have been proposed and demonstrated for computation.

The first approach can be characterized as "chemical computing", in which a series of chemical reactions corresponds to a computation, with the final products of the reactions representing the answer. The most well known example of this is the use of DNA to compute a solution to the traveling salesman problem (a problem that is well known for the simplicity with which it can be stated, yet the exponential growth of computing power required to solve successively more complex cases). In November 2001 a group in Israel demonstrated a "computer in a test tube", based on reactions involving DNA, that was capable of performing a number of basic computational tasks.

The advantage of this technique is massive parallelism. The disadvantage is that each step requires a long time, and a computation can consume a lot of very expensive chemicals. This will probably never become a general computing procedure, but it provides interesting insights into both computer science and chemistry.

The second approach is to use molecules as the "host" for nuclear spins that form the qubits in a nuclear magnetic resonance-based quantum computer. This approach was pioneered by Isaac Chuang, now at MIT. It is interesting in that it can be used to demonstrate various quantum computing algorithms, such as the factoring of 15 by the Shor algorithm recently demonstrated by IBM using molecules in a test tube (effectively) acting as a 7-qubit quantum computer. However, the general consensus is that this approach will not be able to scale up to a computationally useful number of qubits.

Finally, there is molecular electronics, which is the utilization of a molecule or group of molecules as an electronic device in a circuit. Molecular electronics was effectively founded by Mark Ratner and Avi Aviram in 1974, when they suggested a molecular structure that could act as a diode, and further described the theory that explained why this was reasonable. The field was long and slow in developing, with very little work being done until the early 1990s when Mark Read and Jim Tour started to do some serious experiments and also promote the idea that organic molecules could be electronic devices. In the late 1990s, Read and Tour demonstrated a system of about 1000 molecules in a small-diameter monolayer film that had the interesting property of a negative differential resistance.

The US's Defense Advanced Research Projects Agency has supported a program called "Moletronics" since 1999 that has spurred a number of further advances. A collaboration between the University of California at Los Angeles (UCLA) and Hewlett-Packard demonstrated that a monolayer film of molecules between two electrodes could act as a switch, and has since had several patents awarded that show how to build memories from crossbar arrays of such molecular switches, how to address elements in an array constructed from nanowires without needing nanometer positioning accuracy, and how to take a regular crossbar array and configure it into a general circuit.

Many other groups are now actively engaged in this field. In 2001, a group from Bell Labs reported a transistor-like structure that used a monolayer of molecules as the active component of the device. Each group that is working in this area has demonstrated that molecules have interesting and potentially useful electronic properties, and each is pursuing a unique strategy to turn molecular systems into working circuits. At the moment it is too soon to choose which strategy will win out in the end, but the fact that there are so many promising results and options demonstrates that molecular electronics is no fantasy, even if it is still at the fundamental research stage. After a period of further diversification and scientific understanding, it is likely that there will be a convergence and that actual molecular electronic circuits will incorporate aspects of many of the current approaches that are being explored.

Ultimately, the potential is great—bit densities for molecular logic and memory components could be on the order of a terabit/cm2 (6.5 terabits/in2). Switching speeds could get down into the range of a few picoseconds (about 1000 times faster than current DRAM). With such switching rates and densities, the power required to do the switching has to be kept very low to avoid heat dissipation problems.

