QUANTUM TUNNELING NEMS

3D MONOLITHIC DEVICES UTILIZING QUANTUM TUNNELING BETWEEN 2D ARRAYS OF QUASI–1D NANOWIRES

M.T. Michalewicz[1], P. Glowacki[1], Z. Rymuza[2], N. Lumpkin[3], S. Bremner[3], and E. Radlinska[4]

1 Q1Quantum Precision Instruments Asia Pte Ltd, 14A Prince George's Park, Singapore – 2Technical University of Warsaw, Warsaw, Poland – 3Cavendish Laboratory, The University of Cambridge, UK – 4Department of Applied Mathematics, The Australian National University, Australia

ABSTRACT

Quantum tunneling is an exceedingly sensitive probe of inter-electrode separation, electrode area, the type of electrode material and the nature of intervening insulator. Our devices are based on variable overlap area of the quasi 1D–nanowires[1,2], electrodes placed on two opposing atomically flat surfaces. A generic nanoTrek® device is composed of two plates separated by a very thin layer of insulator, e.g. soft-matter spacer, air, vacuum. Several hundred to many thousands quasi-1D nanowires are deposited on each plate. The device can be thought of as a 2D plate/insulating layer (liquid)/ 2D plate sandwich. The nanowires on the two opposing surfaces facing each other and aligned with each other form elongated electrodes in the tunneling process. We have built and successfully tested devices composed of two individual Si chips separated with monolayer of soft-matter spacer[3,4,5]

In this poster we describe the concept leading to 3D monolithic nanoTrek® device specifically suited for sensing dynamic quantities. Both 2D substrates are part of one monolithic unit. One plate is suspended on etched beams. Depending on desired functionality or performance there can be one to four beams with width-to-length-to-thickness ratios designed for specific device sensitivity. Nanowires are fabricated on the top surface of the larger, bottom plate and, opposing them, at the bottom surface of a movable, top plate. Separation between the plates is in the range of 1–10 nm. We discuss several different candidate processes suitable for fabrication of our monolithic devices.

INTRODUCTION

Quantum Precision Instruments Inc. (Quantum-π) proposes to develop a new type of Nano Electro-Mechanical System (NEMS) vibration sensors based on quantum tunneling between arrays of nanowires. Our nanoTrek® devices are based on variable overlap area of the quasi-1D nanowire electrodes placed on two opposing atomically flat surfaces[1,2]. Apart of building a standalone vibration sensor we will address issues of distributed power supply, either through energy harvesting or storage, and of building a large wired and wireless networks of sensors, with a goal of delivering a network system for structural health monitoring. Our sensors utilize exceedingly sensitive physical phenomenon of quantum tunneling hence will be superior in accuracy, smaller in size and of lower cost than existing sensors.

Eighty six years after the proposal of quantum mechanics by M. Planck in 1900 G. Binnig and H. Rohrer were awarded the Nobel Prize in Physics for constructing and successful demonstration of the Scanning Tunneling Microscope (STM). Very soon after their feat several groups attempted to build cantilever or beam geometry sensors based on quantum tunneling through a variable inter–electrode gap[7,8,9,10,11]. Despite considerable efforts and some successes, cantilever geometry quantum tunneling sensors have not achieved broad commercial success. Here, we propose an entirely different principle of operation for quantum tunneling devices. Unlike their commercially less successful predecessors Quantum-π's nanoTrek devices are not cantilever or beam devices. They are based on a constant inter–electrode separation, but variable area tunneling between two sets of nanowire arrays deposited on two substrates. Hence, Quantum-π sensors are unlike any previously built or designed devices[13,14,15,16,17,18,19].

TECHNICAL INNOVATION

Quantum-π has the intellectual property rights[2,20] to technology for exceedingly sensitive quantum tunneling nanoTrek NEMS sensors. Arrays of quasi-1D nanowires are fabricated on two substrates. When a small bias is applied between the two sets of nanowires in essentially parallel configuration, a tunneling current flows between them. The substrates are allowed to slide laterally with respect to each other, with normal separation kept constant. The tunnel current is an extremely sensitive measure of an overlap area of nanowires on one and the opposing substrate. nanoTrek devices unlike their commercially less successful predecessors[7,8,9,10,11] are not cantilever or beam devices.

EVIDENCE OF SCIENTIFIC FEASIBILITY

This new and unique technology has never been implemented before, so there are technical challenges to overcome:

- Developing techniques for fabricating 3D monolithic devices with 2D arrays of quasi-1D nanowires on opposing (internal, hidden) surfaces;
- Fabrication of nanowires, 10–90 nm wide with nearly atomically smooth surfaces with no pin-holes and surface roughness;
- Developing packages for stand alone sensors that can be only 50-100 micrometer in size;
- Developing robust Digital Signal Processing for the low-level electrical nanosystems;
- Optimizing application specific vibrational response of nanosensors;
- Integrating sensing, power and communication on a single chip in a single package.

Despite these technical challenges, the theoretical and experimental bases of the project are well substantiated. Our first working linear encoder of position based on quantum tunneling has already been demonstrated. The sensing element consists of 12,000 nanowires, each 90 nm wide and 5 mm long (~1:55,000 aspect ratio), on a sensing area of 5x4.3 mm. Here we describe our plan to substantially extend this early work to:

i) build dynamic sensors of vibration
ii) build 3D monolithic devices with 2D arrays of quasi-1D nanowires
iii) on-chip integrate micro-power and controllers, and
iv) build a network consisting of large number of nanoTrek® sensors.

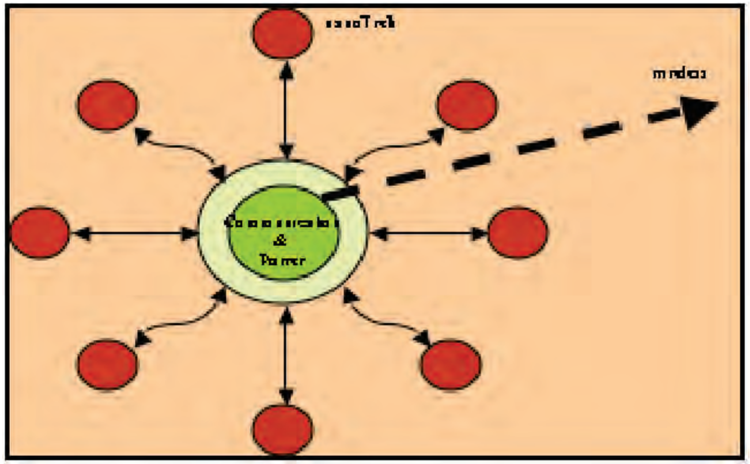

Figure 1: Simple nanoTrek system concept with sensors, power and communication

Technical Objectives

Quantum-π proposes to develop processes and technology leading to eventual manufacture of commercial product, based on its novel nanoTrek technology. A rudimentary proof of concept for the microfabrication of conducting nanowires for the nanoTrek devices has been

Figure 2: An early GaAs device, the black chip on a standard ceramic mount, is shown in comparison to an Australian 5 cents coin. The nanoTrek chip is appr. 1 mm2, and has an irregular shape as it was cleaved by hand. The active section containing the nanowires occupies the central area of the chip and is only 75 x 75 m in size. It is not visible to the naked eye directly but a tiny green speck of light diffracted from the nanowires can be seen near the middle of the chip.

performed by Dr N. Lumpkin and Dr S. Bremner, at the Cavendish Laboratory, The University of Cambridge, UK. Au/Ti nanowires were fabricated on GaAs substrates. These nanowires were 0.5 m wide and 75 m long and the pitch was 1.6 m. The entire sensing area was 75x75 m in size. Figure 2 and Figure 3 depict examples of the nanoTrek proof of concept prototype devices fabricated at Cambridge and characterised at the ANU.

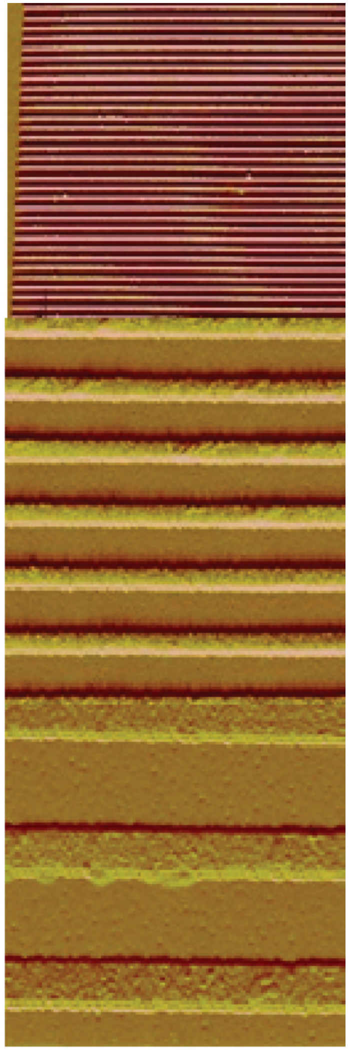

Figure 3: AFM image of the TiAu nanowires deposited on the GaAs substrates – nanoTrek plates. TiAu nanowires are the active element of nanoTrek devices. (three different magnifications). AFM imaging - Dr E. Radlinska, ANU

Technical Approach

Our goal is to substantially extend proof-of-concept work conducted so far and to build 3D monolithic dynamic devices depicted below (N.B. these are concept diagrams – the top plate is actually a part or larger "chip" – as drawn and do not protrude on "columnar" structures depicted here – and to integrate them in a wired or wireless sensor networks.

Figure 5 represents suggested process flow for fabrication of 3D monolithic structures like those in Figure 4, including the nanowire arrays and electrical connections:

Quantum-π has developed alternative fabrication hybrid processes for 3D device fabrication. three alternative approaches have been identified:

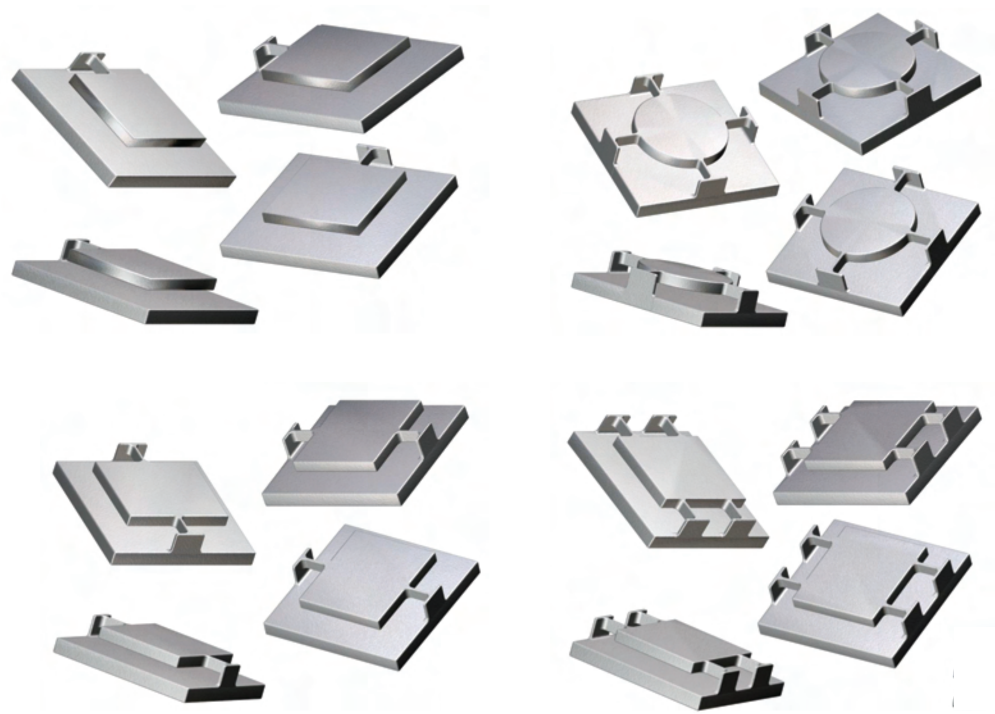

Figure 4 The figure depicts perspective views of 3D nanoTrek monolithically integrated devices. The all important arrays of embedded nanowires on the bottom surface of the top plate and on the top surface of bottom substrate are not depicted here.

i) Fabrication of 3D monolithic structures, ii) hybrid processes for 3D device fabrication, and iii) planar process of fabrication of two separate plates with arrays of nanowires with soft-matter spacer between the plates.
We plan to start above described R&D plan in September 2007.

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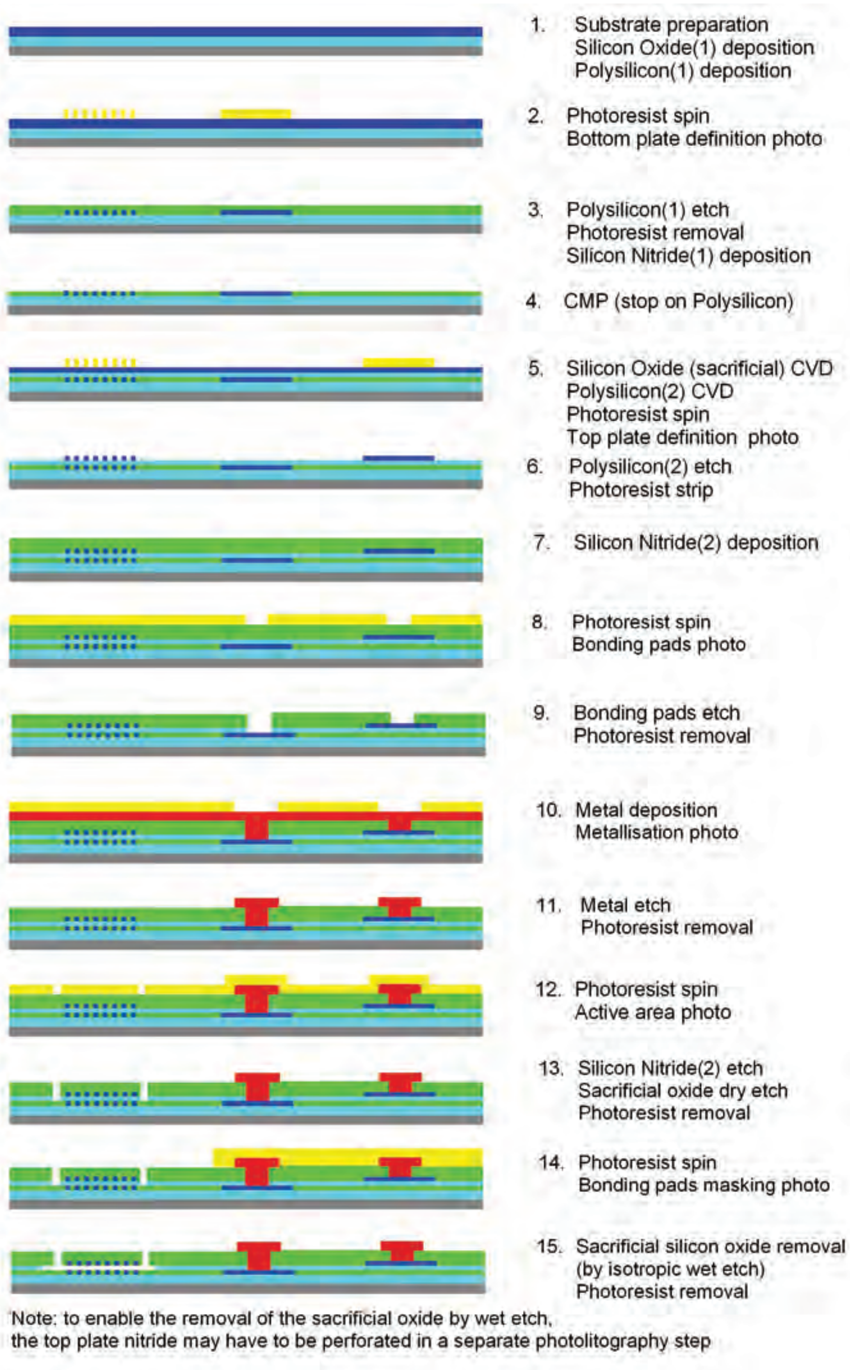
Figure 5: Process steps for nanoTrek 3D monolithic integration including nanowires



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