Silicon Nanowire-Based Nanoactuator

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***Abstract*-A new class of nanoactuator based on the bimetal thermal effect of chromium-coated silicon nanowire has been demonstrated. The nanoactuator is fabricated by the localized synthesis process of silicon nanowires and coating them with a 5nm-thick layer of chromium. Actuation occurs when the supporting microheater is heated locally by resistive joule heating which causes the nanowires to deflect due to the difference in the coefficient of thermal expansion (CTE) between chromium and silicon. Experimentally, the maximum measured deflection of a 3.66µm-long silicon nanowire is 1.52µm under a power input of 31.4mW to the microheater.**

INTRODUCTION

The synthesis, assembly and property investigation of nanowire have been the major research focuses in recent years [1,2,3]. With the emerging technology of nanowire production, designing an actuating application based on these wires could advance nanotechnology to a new level. On the other hand, the mechanism of thermal actuation has been widely investigated and implemented to build MEMS actuators [4]. The scaling effect down to the nano scale implies higher surface-area to volume ratio and could enhance the performances of existing micro thermal actuating devices, such as thermally actuated optical switches. The ability to produce nanostructures by utilizing the already well developed microfabrication technology is of advantage for the production process as well as for the integration of NEMS, MEMS, and ICs in constructing a fully functional device. We present the combination of thermal actuation principle and the insĭtu fabrication nanotechnology for a thermally driven nanoactuator in this work.

WORKING PRINCIPLE AND EXPERIMENTS

Fig. 1 shows the schematic illustration of the use of silicon nanowires for thermal actuation. Silicon nanowires are first fabricated by the localized synthesis process [1] as shown in Fig. 1. The bi-layer structure is constructed by evaporating a 5nm-thick layer of chromium onto the silicon nanowires. The CTE of chromium and silicon is $6x10^{-6}$/K and $2.66x10^{-6}$/K respectively, i.e. for every degree Kelvin rise in temperature, the chromium layer expands 2.3 times more than the silicon nanowires. This difference in the CTEs actuates the nanostructure when the microbridge is heated by resistive joule heating as shown in Fig. 1.

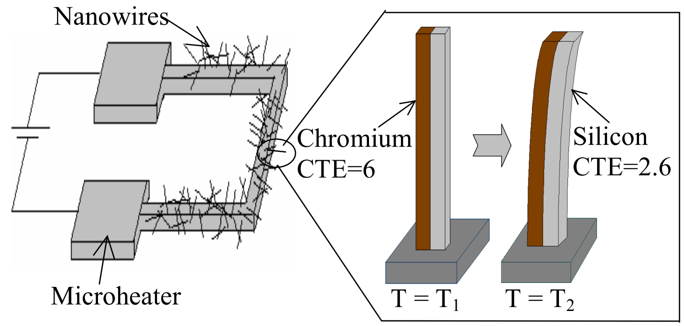

Figure 1. Schematic illustration of actuation process.

Experimentally, the silicon nanowires were first grown on a 50µm-thick, 2µm-wide and 150µm-long U-shape suspended microheater that was fabricated by a one-mask process on a SOI wafer. The typical dimensions of these nanowires are between 30-80nm in diameter and up to 10µm in length. Due to the small dimension of these nanowires, the actuation process can only be carried out and observed in a Scanning Electron Microscope (SEM). When power is supplied to the supporting microheater, resistive joule heating raises the temperature of the microheater. Heat is transferred from the microheater to the nanowires by conduction. The temperature rise in the nanowires then causes the nanowires to deflect.

Fig. 2 and 3 show the operation of nanoactuators before actuation (no voltage) and after actuation (3.32V input). At the center of the circle only a single nanowire is identified. However, there are in fact two nanowires as seen clearly after the actuation process in Fig. 3. The tips of the two nanowires circled in the pictures are observed to deflect approximately 40nm. This measurement is taken directly from the SEM photos without taking the viewing angle effect into account, i.e. if the deflection is not perpendicular to the viewing plane of the SEM, only partial deflection can be observed from the SEM photos. A more detail record is obtained on a different sample as shown in Fig. 4. Fig. 5 shows the recorded actuation result of the tip movement of a 3.66µm long nanoactuator pointed in Fig. 4 with respect to the input power on the microheater. A maximum deflection of 1.52µm is achieved under a power input of 31.4mW. The deflection profile appears to follow a linear relationship with the power input up to 15mW. After this point, the nanoactuator only deflects slightly, 0.15µm compares to 1.37µm initial deflection, by the same 15mW increase of power.

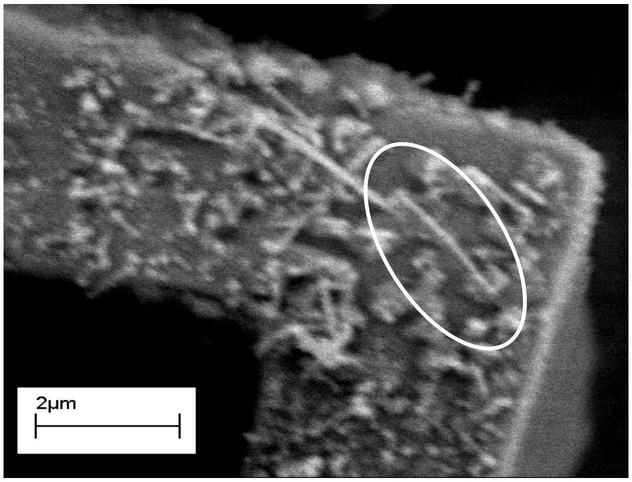

Figure 2. Silicon nanowires on top of a microheater before actuation (no applied voltage). There are actually two nanowires in the circle (as seen in Fig. 3). Their diameter is estimated to be 40nm.

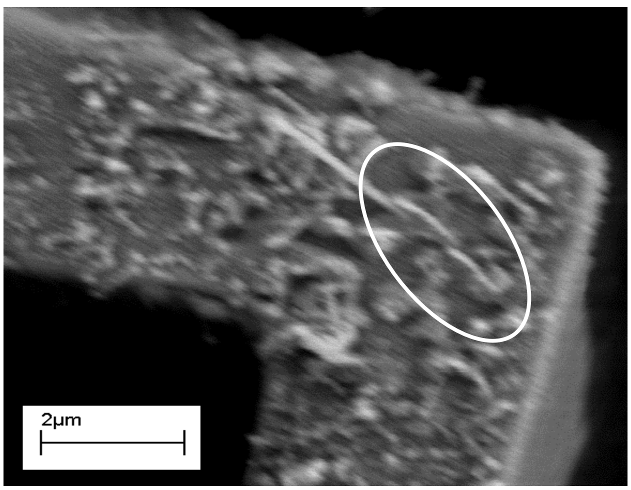

Figure 3. After the microheater is heated up (3.32V input), we can clearly identified two nanowires. They are observed to bend about 40nm.

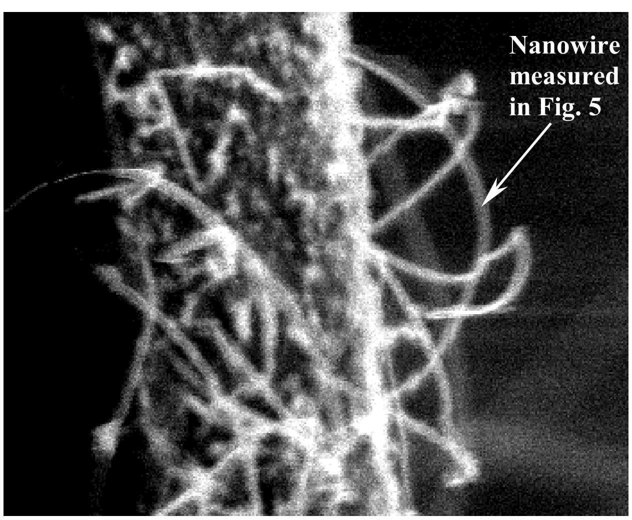

Figure 4. Silicon nanowire used to generate deflection profile in Fig. 5.

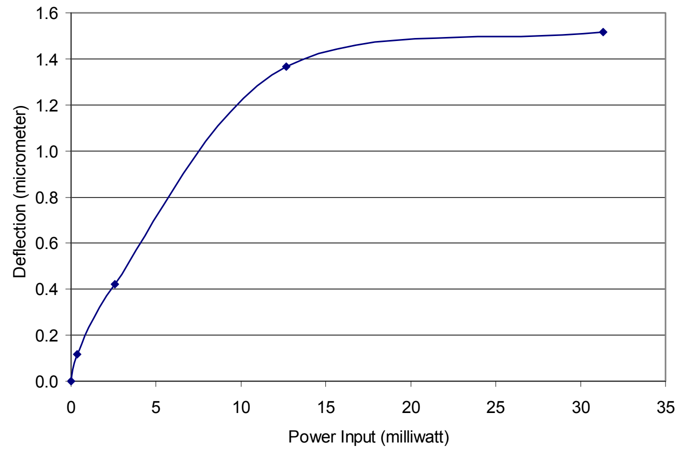

Figure 5. Estimated tip deflection of nanoactuator versus the input power on the microheater.

The nonlinear relationship at higher power is due to three factors: (1) As the temperature gets higher, heat loss due to radiation becomes significant, this leads to a smaller temperature increase on the nanoactuator as the power is increased; (2) the CTE to temperature profile of silicon becomes nonlinear as the temperature gets higher (higher than 500˚C), after this point the CTE only increases slightly as the temperature increases; (3) obstruction from the nearby nanowires that overlaps the target nanowire being investigated after initial actuation also affects the deflection of the nanoactuator.

Since the tip deflection is measured directly from the SEM image, the effect of the viewing angle with respect to the nanoactuator and its actuating direction is not taken into account. This could lead to deviations from the actual deflection of the nanoactuator. Furthermore, these nanowires have been grown without any fixed direction such that they deflect randomly in all directions depending on their initial condition. To control these nanoactuators in having a uniform movement as a whole and to have a better scheme to measure the deflection are some of the directions to work with in the future.

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