Multiplexed Free-standing Nanowire Transistor Bioprobe for Intracellular Recording: A General Fabrication Strategy

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Introduction: Recent advance in free-standing nanowire transistor bioprobes opens up new opportunities of accurately interfacing spatially unobstructed nanoscale sensors with live cells. However, the existing fabrication procedures face efficiency and yield limitations when working with more complex nanoscale building blocks to integrate, for example, multiplexed recordings or additional functionalities. To date, only single-kinked silicon nanowires have been successfully used in such probes [1]. Here we establish a general fabrication strategy to mitigate such limitations, with which synthetically designed complex nanoscale building blocks can be readily used without causing significant penalty in yield or fabrication time, and the geometry of the probe can be freely optimized based on the orientation and structure of the building blocks. Using this new fabrication framework, we demonstrate the first multiplexed free-standing bioprobe based on w-shaped silicon kinked nanowires which are synthetically integrated with two nanoscale field-effect transistor devices. Simultaneous recording of intracellular action potentials from both devices have been obtained of a single spontaneously beating cardiomyocytes.

Materials and Methods: Two nanoscale field-effect transistors (nanoFETs) are synthetically integrated at the elbows of the silicon nanowire with three kinks in *trans*-orientations by metal nanoparticle-catalyzed chemical-vapor deposition (CVD). Using these nanowires as the building blocks, a 4-stage general micro/nano-fabrication framework was developed to construct free-standing probes with dual-nanoFETs at the tip. Spontaneously beating cultured rat neonatal cardiomyocytes were used for intracellular recording following previously established protocols [1].

Results and Discussion: The distance *d* between the two nanoFETs can be accurately adjusted by controlling the growth time of the nanowire arm *L* between adjacent kinks (Figure 1a). The free-standing probe can be mounted and accurately manipulated on a micro-manipulator, and the dual-nanoFETs at the tip are fully protected by a photosensitive cap which will be removed immediately before recording (Figure 1b). Simultaneous intracellular action potentials have been obtained from the same cell from both devices (Figure 1c).

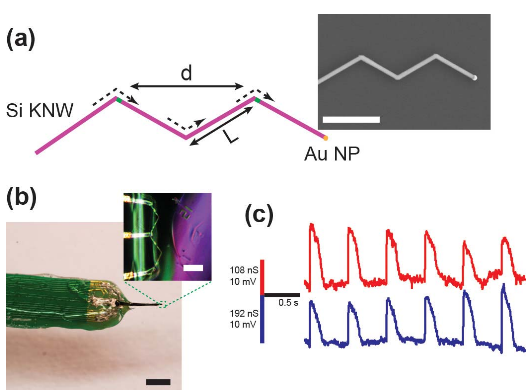

Figure 1. (a) Left: Schematic of the accurate synthetic design of w-shaped silicon KNW. The dotted arrows denote the growth direction; the green sections mark the position of the nanoFETs. The arm length between adjacent kinks (L) and distance between nanoFETs (d) are controlled by arm growth time and the kink angles. Right: representative SEM images of KNWs synthesized using 150 nm Au-NPs as catalysts with arm growth times of 2min. Scale bars: 2 µm. **(b)** Digital camera image of a fully assembled probe on the printed circuit-board connector. Scale bar: 2 mm. Inset: Dark-field optical image of the suspending Si KNW nanoFET embedded in the photoresist protection cap at the tip of the probe. Scale bar: 10 µm. **(c)** Data recorded simultaneously from both nanoFETs in contact with the same spontaneously beating cardiomyocyte. Both devices showed signals with intracellular characteristics.

Conclusions: We have demonstrated the first free-standing dual-nanoFET bioprobe based on w-shaped KNWs, and successfully obtained the first multiplexed intracellular recording from the same cell using a single probe. Our new fabrication procedures have migitaged the yield and efficiency limitations in previous fabrication procedures and can be used as a general framework for preparation of free-standing bioprobes with optimal geometry based on any complex bottom-up designed nanoelectronic materials, opening up new opportunities in integrating additional functionalities and performance in free-standing nanoelectronic bioprobes by innovative synthetic designs of nanoscale building blocks.

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References:
[1] Qing, Q. et. al, *Nat. Nanotechnol.*, **2014**, **9**, 142-147.