

Chapter 41

Nanorobot–Based Handling and Transfer of Individual Silicon Nanowires

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ABSTRACT

Presented is a new experimental implementation for well-directed handling of silicon nanowires with diameters of less than 100 nm and length of up to 10 μm . Handling device is a robotic setup of several centimeters in size and nanometer accuracy, mounted inside a SEM (Scanning Electron Microscopy) chamber. The actual transfer of the nanowires is done by this setup from a production substrate to a different electrode substrate by using an STM (Scanning Tunneling Microscope) tungsten tip as carrier, gas based adhesive bonding, and FIB (Focused Ion Beam) assisted milling. The goal of this series is the placement on the electrodes in order to facilitate further electrical characterization measurements. The presented handling technique for nanoscale objects facilitates an accurate picking and placing of individual nanowires on the one hand and a transfer over several centimeters to a complete different substrate on the other hand. Advantages, prospects and limits are investigated particularly with regard to a handling automation for applications.

INTRODUCTION

Over the last years, objects with dimensions in the nanometer range have become more and more important. Especially, carbon nanotubes, different types of metallic, semi-conducting, insulating and metal-alloy nanowires offer unique properties due to their atomic configuration as well as their tiny

size, which mainly effects the high surface-to-volume-ratio. Nanotubes and nanowires are predestinated to improve sensors and even actuators in several ways. This does not only concern size, sensitivity, and performance (Björk et al., 2008), but also energy consumption and the prospects of new material properties on the nanometer scale caused by quantum mechanics, such as ballistic electron transport (Krüger, 2007). Nanotubes and nanowires are discussed as crucial parts in

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novel sensors, actuators, and ICs based on these structures. All application fields of sensors are addressed: temperature, flow, chemistry, biosensors, pressure, strains, resonators, and antennas (Ekinci, 2005; Hüttel et al., 2009; Popov et al., 2008; Rutherglen & Burke, 2009; Sinha et al., 2006; Yogeswaran & Chen, 2008). Especially, silicon nanowires are highly discussed in the entire microelectronics- and MEMS industry; they are claimed to work as light traps for solar cells (Garnett & Yang, 2010), tunneling field effects transistors (Björk et al., 2008), transducers for biological/chemical sensors and foremost transducers for all kinds of nano-electromechanical systems (He et al., 2008; Zheng et al., 2010).

Today, most applications utilizing nanowires rather take advantage of a cluster, than of the particular properties of an individual nanowire. The main reason for this is still the limited ability to place individual nanowires on a certain target spot. Due to all parasitic forces on the nanoscale and the specific problems of all different situations and materials, handling of nanoscale objects is still very challenging.

Several approaches concerning nanoscale handling exist and can be distinguished and classified by different criteria. The most common, because easy controllable, approaches are self-assembly techniques, where chemical or electrochemical components are used to grow or place many wires at the same time: Direct growth is one of the most common approaches for placement. During the chemical vapor deposition, nanowire's grow at the catalyst particles and only there. The structured application of catalyst predetermines the position of the nanowire. Although this technique is well understood and controllable, the major disadvantages are the hardly changeable perpendicular growth direction and process temperatures of more than 600°C (Teo et al., 2003). The dielectrophoresis is another common approach to placing nanowires in certain spots. This technique requires solvents with nanowires and addressable electrodes. Although it is useful for a variety of applications, it is not

capable of installing nanowires in places without electrical contacts or achieving arbitrary orientations (Bishop et al., 2009; Sorgenfrei et al., 2009). Several researchers are investigating mechanical transfer techniques: Pre-aligned nanowires were surrounded and caught by a transfer material, removed from the source and placed on a different sample, where the transfer material can be dissolved. This approach can achieve high throughput and avoids high temperatures, but has the same disadvantages of direct growth. Additionally, the high accuracy of the catalyst placing is destroyed (Eng et al., 2011; Huang et al., 2005).

In contrary to the self-assembly techniques, robotic approaches using end effectors are only able to handle in a serial way. On the other hand, they are the only existing approach to place an individual nanoobject onto a certain spot, without severe demands for the handling conditions. Certainly, a robotic environment is necessary for end effector based handling. This robotic environment can consist of nanorobotic positioning system, acting comparable to a macroscopic robotic system; which can be a flexible robot (Jasper, 2011), or just a positioning stage carrying a sample or an end effector (Klocke & Jones, 2011; Zhang et al., 2012). Alternatively, a more integrated positioning system such as the actuators of an atomic force microscope (AFM) itself can be used to perform pick-and-place manipulations (Kim et al., 2011; Xie et al., 2012). Depending on the environmental conditions of the experiment, both approaches offer particular advantages and disadvantages: A dedicated robotic system can be easily designed according to surrounding conditions such as the SEM vacuum chamber where it is integrated. On the other hand, the usages of an already integrated system takes advantage of a fully working setup, but might be lacking in flexibility in arrangement and integration into a supplementary controlling architecture.

The pick-task itself, can be executed by any type of end effectors able to fasten an object to itself. Therefore, different approaches are exam-

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