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# Nanoprober-based EBIC measurements for nanowire transistor structures

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ABSTRACT

Electron beam induced current (EBIC) measurements can be used to visualize depletion region in semiconductor junction structures. In this work we use a nanoprober setup to create local contacts to nanowire (NW) based tunnel-field-effect-transistors (TFET), which are gated p–i–n diodes, and perform EBIC measurements to investigate dopant diffusion effects in the junction region of TFET structures fabricated with high and low thermal budget. For contacting we use commercial tungsten probes and in-house fabricated conductive diamond tips. The results show that nanoprober based EBIC measurements are a straight forward way to study the functionality of a large number of NWs simultaneously while also allowing to make an in-depth investigation of the junction position as a result of different processing conditions of the nanowire transistors.



## 1. Introduction

Electron beam induced current (EBIC) measurements allow for the direct visualization of the junction depletion region in semiconductor structures in scanning electron microscopy (SEM). It is commonly used for e.g. solar cell defect analysis as electrical contacts to these device structures are readily available [1]. EBIC has also been demonstrated for nanostructures, such as nanowires (NW), but here the contacting is more challenging as it usually requires e-beam lithography and metallization or other laborious techniques [2]. To address these limitations of earlier EBIC measurements, we present in this work a nanoprober based technique for creating direct electrical contacts to nanostructures, such as nanowire transistors, for EBIC measurements.

The so-called nanoprober is a tool where the ability to observe nano-scale objects by SEM is combined with the simultaneous capability to contact, manipulate and perform electrical, mechanical or other kinds of measurements with these objects. The essential part of a nanoprober is the tip which is used to make a contact with the structure under investigation. In EBIC measurements the tip has to provide a good electrical contact with the structure while not obscuring the incident electron beam which is used to generate the EBIC signal. Depending on the structure, two or more tips have to be placed onto the same nano-structure simultaneously. In this work, we use metallic and conductive diamond tips to achieve these goals.

Novel device concepts have recently been introduced to overcome the major challenges which are being faced in downscaling of CMOS technology. One of these is the tunnel-FET (TFET) which is considered as a potential successor of standard MOSFETs especially due to the expected superior (<60 mV/dec) sub-threshold-swing and reduced short-channel effects. This paper introduces the nanoprober based EBIC technique for investigating junction properties of vertical nanowire TFETs [3,4].

## 2. Measurement setup

Our nanoprober setup consists of four Kleindiek MM3A nanomanipulators [5], equipped with low current measurements units, and a Kleindiek LT3310 linear sample stage placed in an FEI XL30 SEM vacuum chamber (Fig. 1). The nanomanipulators allows for contacting the sample over the centimeter range with nanometer precision. For electrical measurements the manipulator tips can be connected to various characterization tools, such as a Keithley 4200-SCS parameter analyzer or EBIC amplifier, via vacuum feedthroughs.

Two types of probes are used in this work: commercial metal tips and in-house fabricated conductive diamond tips. The metal tips are based on a 22-μm diameter tungsten wire with nominal 100-nm tip radius [6] soldered to a 0.5-mm diameter tinned copper shaft for easy manipulation. The in-house fabricated diamond probes consist of planar triangular-shaped conductive diamond tips attached to a 50-μm wide nickel cantilever. The planar geometry allows for a good visibility of the contact point within the SEM while the triangular shape facilitates the placement of several tips in close proximity. The nanocrystalline structure of the diamond

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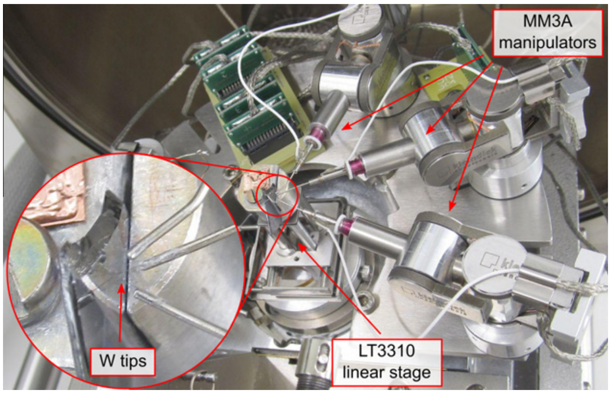


**Fig. 1.** The nanoprober setup.

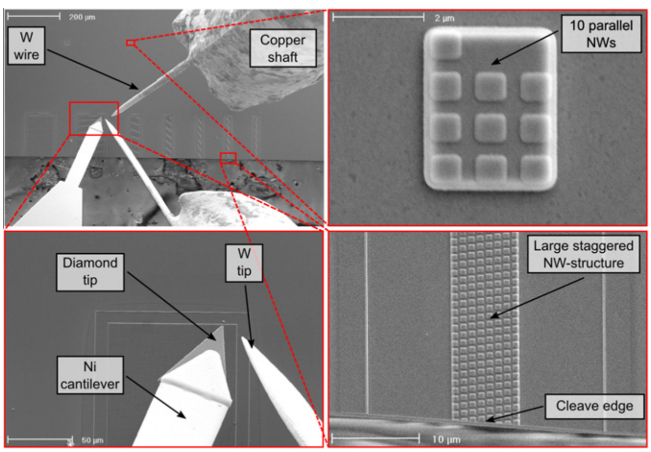


**Fig. 2.** Metal and diamond tips contacting NW structures.

tip results in a very small contact radius at the tip apex enabling a high contact pressure required for direct probing of hard semiconductor materials like silicon and germanium. The fabrication and testing of these diamond tips are described in detail elsewhere [7,8]. Fig. 2 shows two tungsten tips and a triangular planar diamond tip placed on a NW-TFET structure.

## 3. Nanowire structures and sample preparation

The structure of vertical TFETs used in this work is illustrated in Fig. 3 together with a transmission electron microscopy (TEM) image of such a device. The TFET structures are fabricated by a top-down approach and they resemble NW-based vertical $p^+$–$n^-$–$n^+$ diodes. The processing of these NW devices is described in detail in reference [9]. The electrical characterization of the NW devices is performed by nanoprober-based *I–V* measurements and by measuring the carrier distributions with scanning spreading resistance microscopy (SSRM) [10]. While both of these techniques give essential information about the device characteristics, they do not allow simultaneous measurement of a large number of devices in a way planar EBIC imaging does (see Fig. 4).

Two types of NW-TFETs are used in this work. The first type is subjected to a high thermal budget (975 °C, 200 min) during the local oxidation process (LOCOS) while the other type is fabricated with only low thermal budget steps. The NW devices on these samples are located either in small parallel-connected structures of 1–50 NW in each, or in large rectangular areas where individual NWs are arranged in a staggered array. The small structures are intended for *I–V* measurements while the large structures facilitate

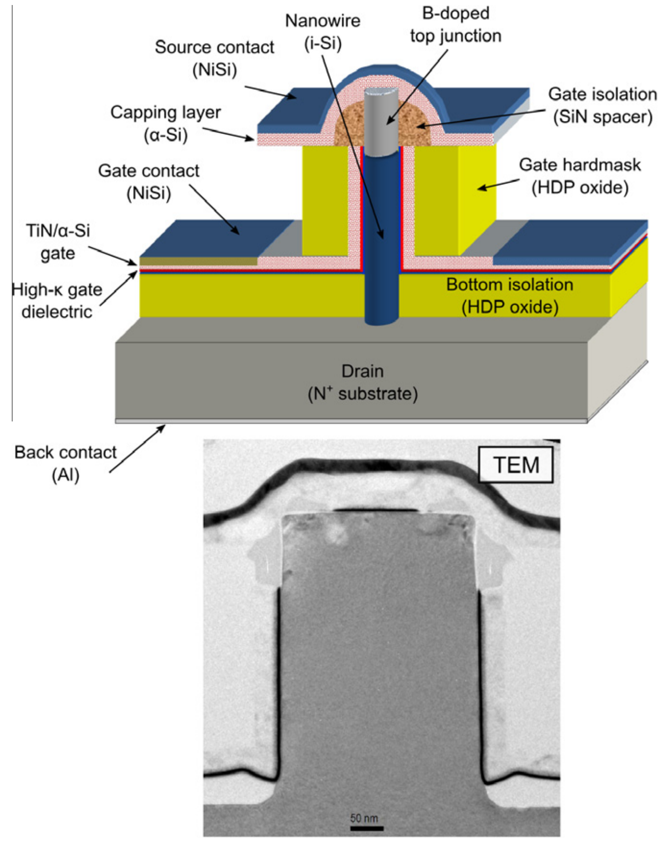


**Fig. 3.** The structure of a nanowire TFET and a TEM cross section of a 300 nm nanowire.

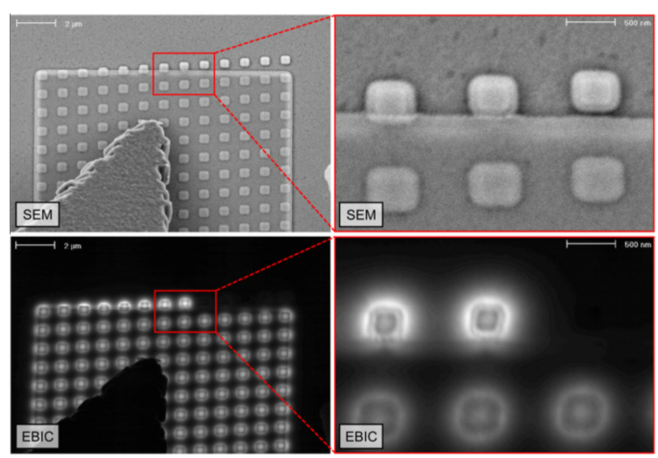


**Fig. 4.** Planar SEM and EBIC images of 300-nm diameter NW structures.

the preparation of cross-sectional samples by manual cleaving. Both large and small structures exist for NW diameters from 500 nm down to 40 nm. In this study we prepare samples for cross sectional EBIC measurements of both small and large structures. For small structures the focused ion beam (FIB) technique is used. This allows for cross-sectional samples which only have one layer of NW structures. Cleaving technique is used preparing cross-sectional samples from large arrays of staggered NWs. Both techniques are applied on both low and high thermal budget samples.

## 4. Measurements

Both tungsten and diamond tips are used for each of the sample types (planar-cross sectional, cleaved-FIB cut, low and high