A Novel Silicon Nanowire-based Electron Detector Utilized in Scanning Electron Microscopes

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ABSTRACT

Electron microscopes are the scientific tools which utilize energetic electron beams (up to 40 keV) to overcome the light limitations in the study of specimen in nanometer scale. Electron detection has an important role in microscopic analysis and known as one of the most important building blocks of scanning electron microscope (SEM). For higher resolutions and better contrast, it is needed that the detector is brought as close to the specimen as possible to collect more secondary electrons. In this paper, a miniaturized detector is introduced utilizing a nano-structured silicon-based device which can be brought to the vicinity of the sample to improve the electron collection. The detector is fabricated by growing silicon nanowires (SiNWs) on a p-type silicon substrate covered by means of a vapor-liquid-solid (VLS) method. It can attract secondary electrons and converts the current to voltage directly. It is a low-cost, low-voltage operation detector which can be integrated on a probe for a proximity measurement.

Keywords: nano-structure, silicon nanowire, scanning electron microscope, electron detector.

1 INTRODUCTION

Originally, microscopy was based on the use of the light microscope and could provide specimen resolutions about 0.2 micrometers. To achieve higher resolutions, an electron source is required instead of light as the illumination source, which allows for resolutions of about few nanometers. Since its invention, electron microscope has been a valuable tool in the development of scientific investigations and it has been contributed in many fields of science such as nanoelectronics, material engineering, biology, medicine and surface engineering [1]. Scanning electron microscope is a type of electron microscopes which is based on the electrtrical measurement of the secondary or backscattered electrons generated on the very top surface of the specimen. The creation of the image is feasible by proper scanning of the electron beam while locating the spot on a display. This nanometer observation is an essential tool to study the surface morphology of the specimens [2]. The use of electron microscopes not only give better resolution, but also due to the nature of electron beam interactions with specimen there are a variety of signals that can be used to provide information regarding characteristics at the surface of a specimen.

In scanning electron microscopy visual inspection of the surface of a specimens utilizes signals of two types, secondary and backscattered electrons. Such secondary and backscattered electrons are constantly being generated from the surface of the specimen. Secondary electrons scattered from the surface are generated due to inelastic collisions of electron beam and the specimen electrons. The energy of the secondary electrons is less than 50 eV [3]. They are exploited to reveal the surface structure of a specimen with a resolution of ~10 nm or better, depending on the beam spot size and the detector [4]. Backscattered electrons are those primary electrons that have been scattered back to the surface due to elastic collision of incident beam and specimen nuclei or electrons. While there are several types of signals that are generated from a specimen under an electron beam the X-ray and Auger signal are typically used to study the composition of a specimen [5].

The SEM image is a two dimensional intensity map in the analog or digital domain. Each image pixel on the display corresponds to a point on the sample, which its brightness is proportional to the signal intensity captured by the detector at each specific point. Unlike optical or transmission electron microscopes, no real image exists in the SEM. The images in the SEM are formed by virtue of electronic synthesis. In an analog scanning system, the beam is moved continuously with a rapid scan along the X-axis (line scan) supplemented by a stepwise slow scan along the Y-axis at predefined number of lines. In digital scanning systems, only discrete beam locations are allowed. The beam is positioned in a particular location and remains there for a fixed time as dwell-time, and then it is moved to the next point. The voltage signal produced by the detector's amplifier is digitized and stored as discrete numerical value in the corresponding computer registry.

Topographical information is mainly provided by secondary electrons which are generated by the interaction of the electron beam with the specimen. Topological features such as flat surfaces, pointed structures and edges significantly have different number of secondary electrons. The conventional Everhart-Thornley (E-T) secondary electron detector mounted in the vacuum chamber in a specific angle relative to the specimen, utilized optical approach, consists of scintillator, maintained at 12 kV positive potential to attract the incoming electrons from the specimen [5], light tube, photomultiplier and amplifier. The photons generated due to the interaction of incoming electrons with the scintillator surface travels through a light tube toward the photomultiplier (PMT) block. The amount of amplification of the photomultiplier tube is controlled by the PMT voltage control (contrast control) [6]. Various controls are possible by manipulating the PMT as well as the magnification of the amplifier. A Faraday cage is also used to improve the distinguish the secondary and backscattered electrons [5].

2 NANOWIRE ELECTRON DETECTOR

Our nano-structured electron detector is fabricated by a three-step process; deposition of a thin gold layer for growing the silicon nanowires by low pressure chemical vapor deposition (LPCVD) system along with doping of wires. Gold, deposited on a p-type silicon substrate acts as a catalyst to enforce the SiNWs growth. Silicon nanowires were grown by a vapor-liquid-solid (VLS) method. Both silicon substrate and SiNWs were highly doped by phosphorus atoms. The SiNWs with the diameter less than 70 nm along with Si substrate were highly doped to act as nm electron sensitive conductive wires. An 8 nm gold thin film has been coated on Si substrate as catalyst layer. Subsequently, the silicon substrate was placed in LPCVD chamber and skein based SiNWs were grown by the assistance of H_2 and SiH_4 gases in 520^{o}C. The SEM image of nanowires has been depicted in Fig. 1.

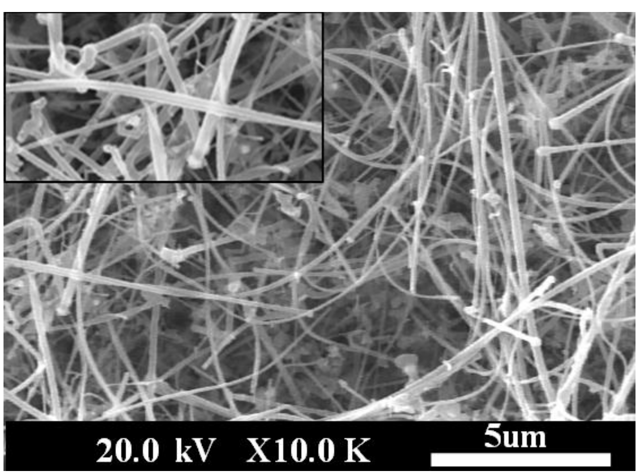

Figure 1: SEM image of the SiNW grown as the electron detector. Inset shows the evolution of skein-type nanowires with a high cross-section to entrap electrons.

The SiNW detector in contrast with conventional detectors collects the electron by a small bias voltage (15V). The collected electrons travel through the nano scale wires toward the doped silicon. A precise picoammeter was utilized to measure the electron beam current. To achieve higher resolution and contrast, nano-structured detector can be approached to the specimen. The schematic of scanning electron microscope equipped with nano-structured electron detector is depicted in Fig. 2. The secondary or backscattered electrons received to the SiNW detector were directly converted to the appropriate output voltage as opposed to E-T detectors where a photomultiplier is used.

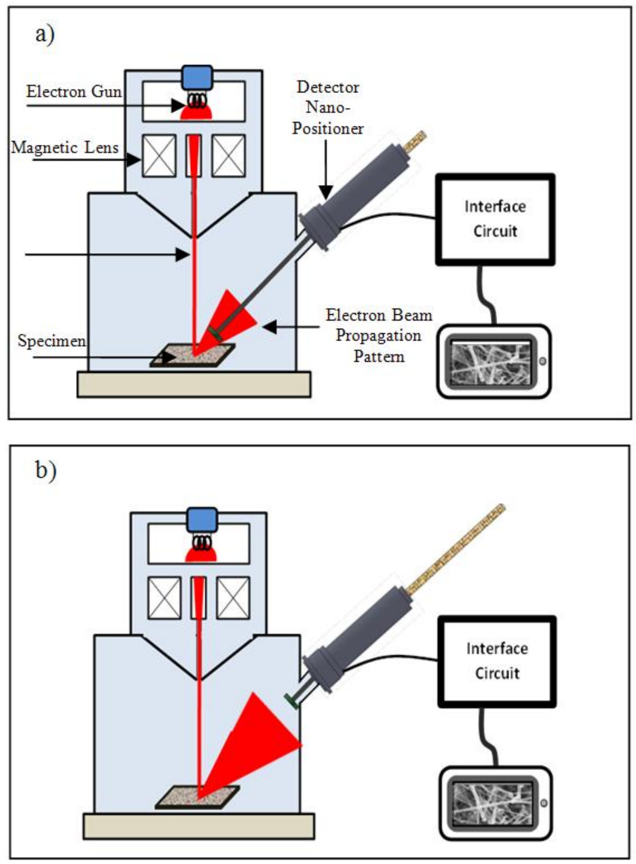

Figure 2: The schematic of scanning electron microscope equipped with nano-structured electron detector. a) Detector mounted on the nano-positioner closed to the specimen, b) conventional E-T detector.

In the Fig. 3 the schematic of the detector along with the signal conditioning circuit is depicted. The conventional E-T detector is usually located at an angle inclined to the sample surface at one side, so that it has a limited angle detection range. The new portable detector can close to the specimen about few centimeters and collect maximum emitted electrons with a high angle detection range. The specifications of the developed detector are summarized in the table 1.

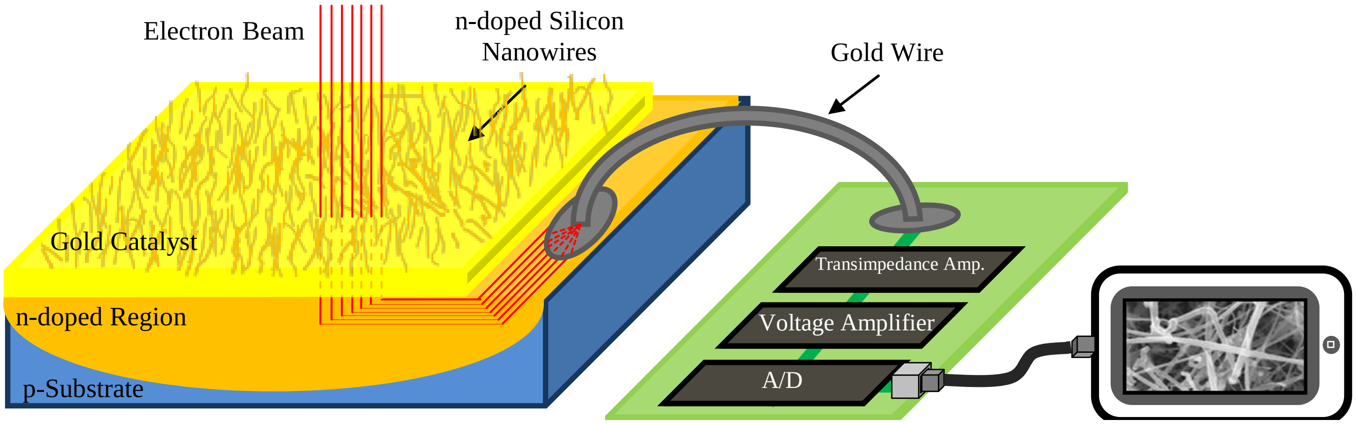

Figure 3: The schematic of the SiNW electron detector along with the signal conditioning circuit.

Parameter	Value
Effective Area	5 mm^2
Detectable Input Electron Energy	5 keV to 30 keV
Electron to Voltage Conversion	0.1 V/nA
Maximum Voltage Output	1.2 V
Supply Voltage	15 V
Picoammeter Acuuracy	2 pA

Table 1: Specifications of the SiNW electron detector.

Fig. 4 depicts the output characteristic of the detector. The nanowire detector mounted on the nano-positioner was placed on a Hitachi S-4160. Moving the electron beam towards the specimen causes more electrons to be emitted from the surface and hence the output voltage of the detector increases. Moreover the increment of detector voltage due to rise in electron beam current was measured. The output voltage diagram shows that the detector is highly sensitive and the pA range of electron beam current could change the detector voltage as tens of mV.

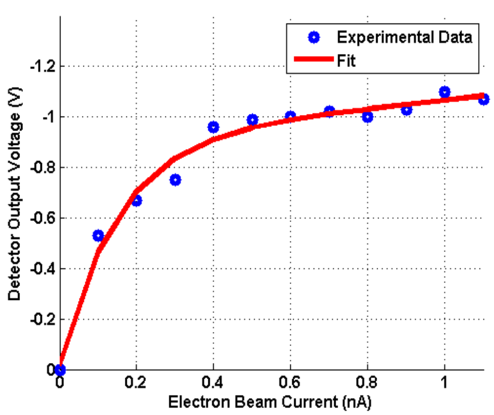

Figure 4: The detector output voltage vs. electron beam current.

3 CONCLUSION

A new electron detector has been devised for scanning electron microscopy based on the use of silicon nanowires. The output characteristics of the detector has been examined by a field emission electron microscope where secondary electron currents of the order of a few pico-amperes have been detected. The ultra small size of such detector makes them suitable for placing at the vicinity of the specimen to improve the signal collection. The side-effect of emitted X-rays on the electron detector as well as the image final resolution of the devices needs to be more thouroughly investigated.

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