Sensors and Actuators B 171–172 (2012) 127–134

Contents lists available at SciVerse ScienceDirect

Sensors and Actuators B: Chemical

journal homepage: www.elsevier.com/locate/snb

Highly sensitive pH measurements using a transistor composed of a large array of parallel silicon nanowires

Gaëlle Lehoucq [a], Paolo Bondavalli [a,*], Stéphane Xavier [a], Pierre Legagneux [a], Paul Abbyad [b], Charles N. Baroud [c], Didier Pribat [d]

[a] Nanocarb Laboratory, Thales Research and Technology, Palaiseau 91767, France
[b] Laboratoire d'Optique et de Biosciences (LOB), Ecole Polytechnique, Palaiseau 91128, France
[c] Laboratoire d'Hydrodynamique (LadHyX), Ecole Polytechnique, Palaiseau 91128, France
[d] Department of Energy, Sungkyunkwan University, 300 Cheongcheon-dong, Suwon, Gyeonggi-do 440-746, Republic of Korea

ARTICLE INFO

Article history:
Received 28 November 2011
Received in revised form 19 January 2012
Accepted 20 January 2012
Available online 14 May 2012

Keywords:
Silicon nanowire
FET
Nanosensors
Biosensing

ABSTRACT

Silicon nanowire field-effect transistors (SiNW FETs) have emerged as good candidates for ultra-sensitive electrical detection of biological species, presenting a label-free alternative to colorimetry and fluorescence techniques. Here, a top-down approach has been used to fabricate the SiNW FETs using silicon-on-insulator (SOI) substrates. As in previous work, a change of the transistor conductance according to the pH of the solution is observed on a large pH interval [3–10.5], even for small variations of 0.1 pH units. The influence of several physico-chemical parameters such as gate voltage and buffer salinity, usually not adequately taken into account in previous papers, is discussed to achieve a better understanding of the detection phenomena.

1. Introduction

The interest for nanosystems resulting from the combination of solid-state nanotechnology and biology has been rapidly increasing in recent years. This alliance opens new perspectives, particularly in the field of chemical and biological sensing. Some interesting devices for this application are transistors based on one-dimensional nanostructures such as silicon nanowires (SiNWs). In contrast with standard fluorescence techniques, field-effect devices can achieve direct and label-free electrical readout of the presence or absence of a molecule. They also have a high potential for integration into miniaturized systems. Moreover, the use of nanowires instead of planar channels in field-effect devices is expected to enhance sensitivity, due to their high surface/volume ratio [1].

A standard field-effect transistor (FET) consists of three terminals: the source, drain, and gate. The current flow between the source and drain is controlled by the voltage applied to the gate electrode. In 1972, Bergveld introduced the first ion sensitive field-effect transistor and showed that the FET channel conductance can be modulated by the change of charge at the silicon–solution interface, in the case of a pH detection [2]. In continuity with this work, several groups reported the monitoring of biological reactions by modifying the gate terminal with molecular receptors or ion-selective membranes for the analyte of interest (e.g. penicillin [3], DNA [4]).

More recently similar experiments with devices based on SiNWs were reported. After demonstrating a pH detection [5], a wide range of biological entities (proteins [6], virus [7], nucleid acids [8]) were monitored with extremely low detection limits. The transistors in these articles were based on one single silicon nanowire, fabricated by a "bottom-up" approach [9]. Indeed, the device fabrication consisted of a sequence of steps that began with nanowire synthesis by chemical vapour deposition (CVD) growth. The nanowires were then harvested and dispersed in ethanol. A drop of this nanowire solution was further deposited on the substrate, followed by the definition of metallic contacts by optical or e-beam lithography. Due to the use of randomly positioned nanowires, this process leads to the fabrication of a limited number of functional devices. This highlights the severe integration issues which hinder widespread application in commercial products. To overcome this problem, an alternative way has been proposed, called the "top-down" approach [10], which consists in patterning and etching nanowires in a silicon layer, using micro and nanolithography techniques, the latter benefiting from the batch manufacturing capabilities of planar microelectronics. Indeed, this approach allows the fabrication of SiNWs on a large area with high density and uniformity. Therefore, we have focused our efforts on the realization and characterization of SiNW-based transistors using this approach

* Corresponding author. Tel.: +33 169415883.
E-mail address: Paolo.Bondavalli@thalesgroup.com (P. Bondavalli).

0925-4005/$ – see front matter
doi:10.1016/j.snb.2012.01.054

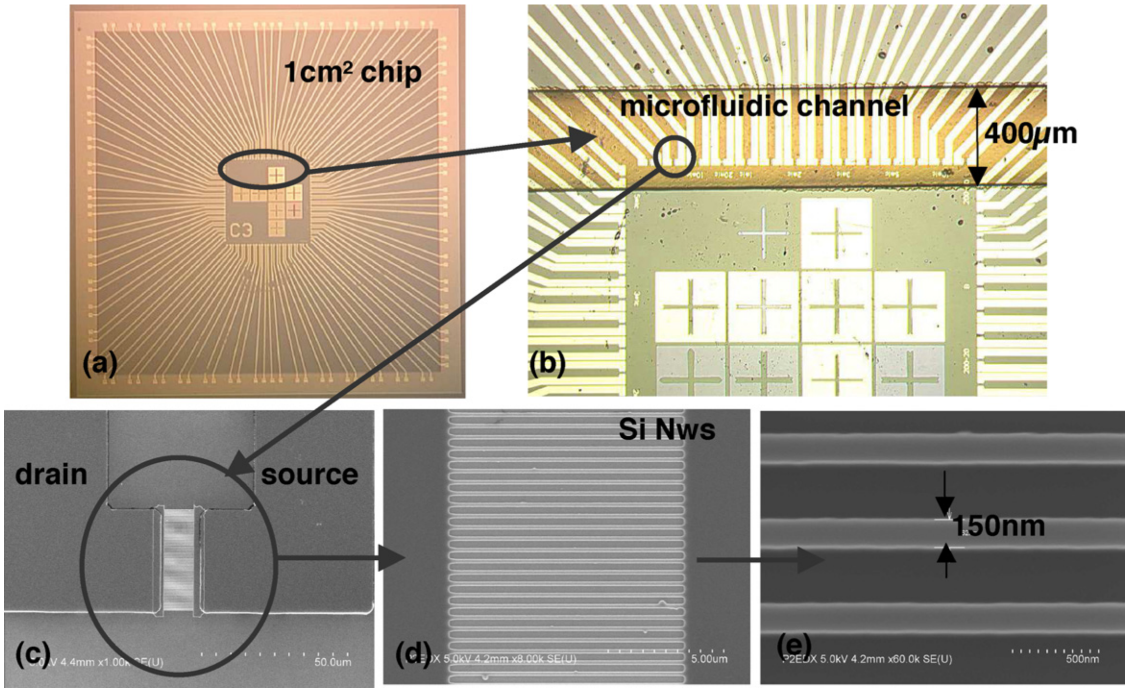

Fig. 1. Overall and detailed views of the top-down fabricated device, with microfluidics and close-ups of the SiNWs. (a) Overall view of the fabricated chip containing 56 transistors. The transistor position is highlighted by the circle. The drain and sources electrode leads spread to the borders of the chip in order to contact the transistors in an easier way. (b) Microfluidic channel integrated on the chip. The PDMS channel is positioned on a series of 14 transistors and has been fixed after exposition to an O_2 plasma. (c) SiNW-based transistor. As shown by this enlarged view, the transistors are composed of quite a few SiNWs. (d) SiNWs fabricated in parallel (transistor channel). (e) detail of SiNWs section. The SiNWs width is 150 nm.

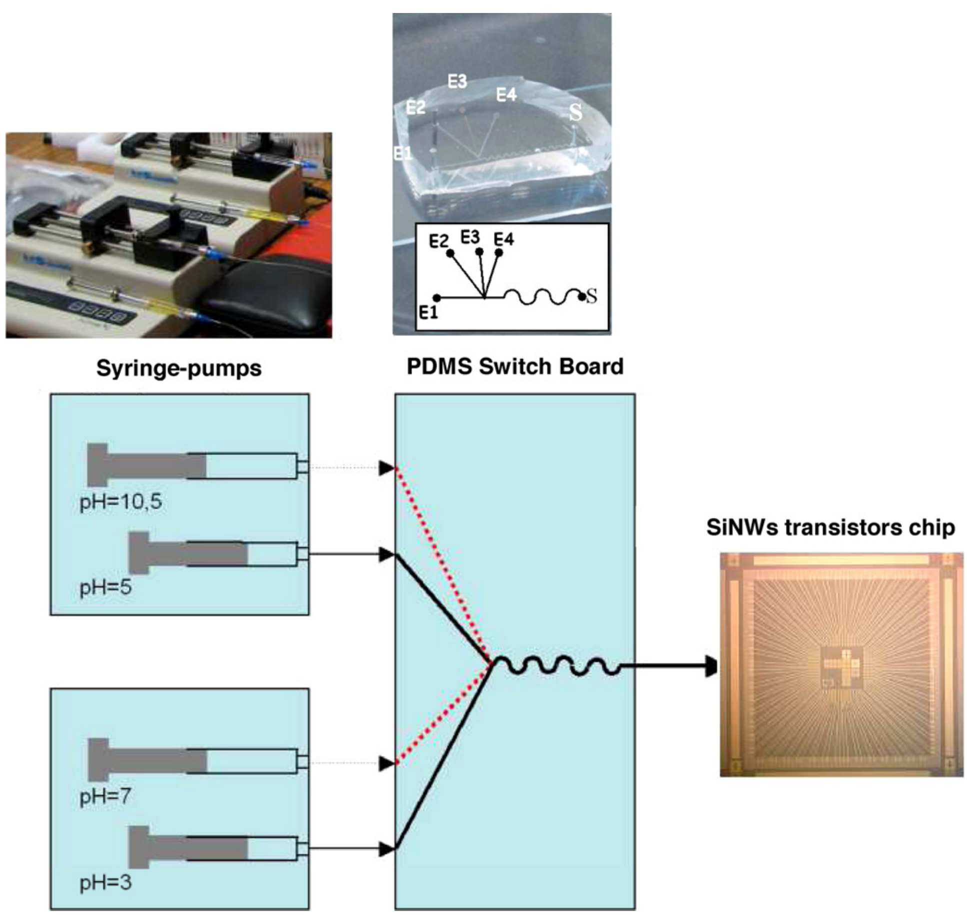

Fig. 2. The experimental set-up for pH testings, using four different pH values. The PDMS switch board with its four entries (E1, E2, E3 and E4) allows a 4-way selection of different chemical solutions at a constant flow rate and solution mixing.