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Abstract

New SiC Microwire-Based Ion Sensitive Junction Field Effect Transistors (SiC ISJFETs) for pH Sensing †

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Abstract: For the first time, we have implemented new kinds of ISFETs based on silicon carbide (SiC). Thanks to its chemical inertness, SiC is an interesting semiconductor for the development of chemically robust and biocompatible ISFETs. The challenge is to replace Si NWFETs for biochemical sensing due to the lack of long-term stability of Si NWs in aqueous solutions. More particularly, we fabricated a micro/nanowire SiC-based ion-sensitive junction field-effect transistor (SiC-ISJFET) and studied its sensitivity to pH variations. The obtained sensitivity reaches 500 mV/pH, making it the first SiC pH sensor with performance equaling that of the latest NWFET Si-based pH sensors.

Keywords: silicon carbide SiC; pH sensor; ISFET

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1. Introduction

Ion sensitive field effect transistors (ISFETs) based on Si nanowires (Si NWs) are undergoing intense research due to their many interesting properties [1]. However, a practical problem that limits their development in the sensing field for long-term use in an aggressive liquid medium (acid, basic, saline) is the lack of chemical inertness of Si NWs. Indeed, the superficial SiO_2 layers can slowly hydrolyze under humid conditions and in aqueous saline solutions [2]. This constitutes a major limiting factor for the stability and reliability of detection signals. This is why alternatives, concerning this material when in direct contact with the solutions and charged biomolecules, are also the subject of current research. A first approach consists in depositing a passivation layer on the Si NWs, such as a metal oxide film with high dielectric constants, i.e., Al_2O_3 [2] or HfO_2 [3], as these present a chemical stability superior to that of silica. Nevertheless, these oxide films may present intrinsic defects likely to introduce surface traps at the Si–oxide film interface, thus degrading the quality of the biological recognition signal [4]. Another approach consists in using materials such as graphene [5], with low mechanical resistance, or MoS_2 [6], the use of which is not eco-friendly. In this context, silicon carbide SiC could easily challenge Si in the development of biosensors, due to its superior characteristics [7]. Notably, SiC NWs exhibit superior chemical inertness in comparison to Si NWs when immersed in physiological solutions [8]. SiC is one of the best biocompatible semiconductors [9], offering prospects for future integration of in vivo biosensors. In the case of pH sensing, to the best of our knowledge, only one work deals with a SiC-based FET [10]. However, in this case, the device is fabricated by a bottom-up process, which is likely to introduce some irreproducibility. In this work, for the first time, we fabricated an all SiC-based ISFET, using a top-down technique, and studied the variation in transfer characteristics with pH variation of solutions. More precisely, we fabricated a micro/nanowire SiC-based ion-sensitive junction field-effect transistor (SiC-ISJFET).

2. Materials and Methods

We implemented conventional microelectronic steps to pattern a three-stacking epilayer structure on top of a 4H-SiC n+ wafer. An illustration of the final device geometry is shown in Figure 1. SiC channel microwires had a length and a thickness of 300 µm and 0.3 µm respectively, with three width values: 0.8 µm, 1 µm and 1.3 µm. Transfer characteristics (I_{DS}-V_{BG}) studied in dry conditions showed good electrical characteristics in terms of back-gate control and an on/off current ratio of 10^5.

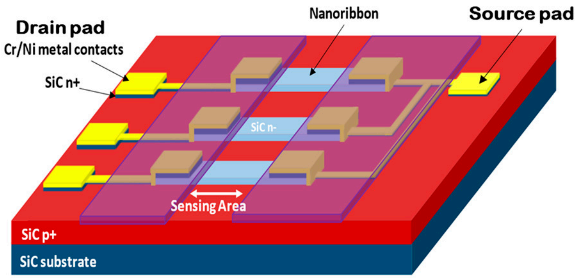

Figure 1. 3D schematic of the SiC ISJFET.

3. Results and Discussion

The sensing performances of the SiC-ISJFET were determined in various pH solutions with an Ag/AgCl reference electrode (or top gate) (schema, Figure 2). A linear shift of (I_{DS}-V_{ref}) curves towards positive Vref values with increasing pH was obtained, demonstrating the effect of pH variations on the electrical characteristics. As a result, a pH sensitivity of 67.2 mV/pH (Figure 2) was obtained, which is slightly superior to the Nernst limit. This sensitivity could be enhanced to 495 mV/pH when operating with a back gate control at a fixed reference electrode value (dual gate mode biasing). Moreover, hysteresis and drift behaviors were studied, showing that our SiC-ISJFET is expected to be promising as a new biosensor.

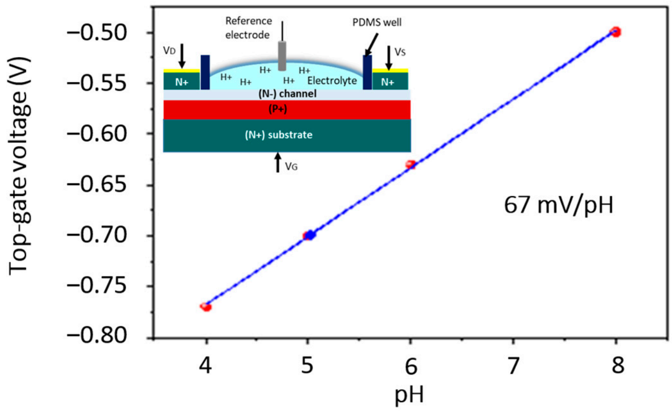

Figure 2. pH sensitivity obtained from IDS-Vref curves.

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Conflicts of Interest: The authors declare no conflicts of interest.

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