Engineering electrical properties of Silicon nanowires by focused electron beam induced processing with Chlorine

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Nanomaterials such as Silicon nanowires (Si-NWs) and semiconductor nanocrystals are highly prospective materials for nanooptics and nanoelectronics. Especially tailoring the optical and electrical properties is a topic that has gained increasing interest in the scientific community. Engineering the band gap of nanowires of a given diameter by utilizing the chemical modification of the nanowire's surface are currently discussed as new approaches to fabricate new devices[1]. It is expected that the partial or full surface chlorination of Silicon nanocrystals can be used to control the position of electronic levels[2]. This effects have been calculated in theoretical studies[1,2,3].

In this work for the first time experimental evidence and an application with Si-NWs is provided, which supports these theoretical studies of the band gab change by the surface chlorination of Si-nanocrystals. Si-NWs produced by VLS growth were contacted by Cr/Au pads fabricated by photo-, e-beam lithography and RF-plasma sputter techniques. The electrical properties of these nanowires with a diameter between 90 and 230 nm were assessed by I-V measurements and displayed an ohmic behavior (Fig.3. left). These Si-NWs were exposed to a chlorine atmosphere in the range of 6x0E-5 mbar in a vacuum chamber but no change of properties was observed. Only upon exposure to the focused electron beam the surface of the Si-NW was reacting with the chlorine and after longer irradiation (more than 7 min) a significant reduction of the diameter of the Si-NW due to etching was observed. This proves that electron irradiation resulted in a surface activation leading to a surface reaction with the chlorine. For shorter electron beam exposures (below 5 minutes) the diameter reduction was not observed in the SEM, however, an electron-induced surface reaction can be assumed. We exposed only half of the length (1.4 µm) of the nanowire between the contacts to the electron beam (for 3 min) as shown in (Fig 2.a). The magnified section shows no difference in the diameter between the Si-NW before processing (Fig. 2.b.) and after processing (Fig. 2.c.). I-V measurements were carried out on the Si-NW after the Cl-processing and a dramatic change from an ohmic behavior to a diode-like behavior additional to an increase in the electrical resistance was measured (Fig.3. right). This result was confirmed by several repetitions on different Si-NWs and can only be explained by a change of the electronic properties of the Cl-treated section of the wire. Based on the theoretical studies [2,3,4] it can be strongly assumed that the band gap of the Cl-processed section is smaller than the band gap of the unprocessed section, at least in the surface layers, giving rise to a heterojunction diode, which explains the diode-like electrical behavior after the Cl-processing. Also results of TEM and EDX will be presented and related to the electrical behavior. Potential nanoelectronic and nanooptical device applications will be discussed.

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[3] Yeshi Ma, Xiaobo Chen, Xiaodong Pi*, and Deren Yang, J. Phys. Chem. C **115** (26), 12822 (2011).

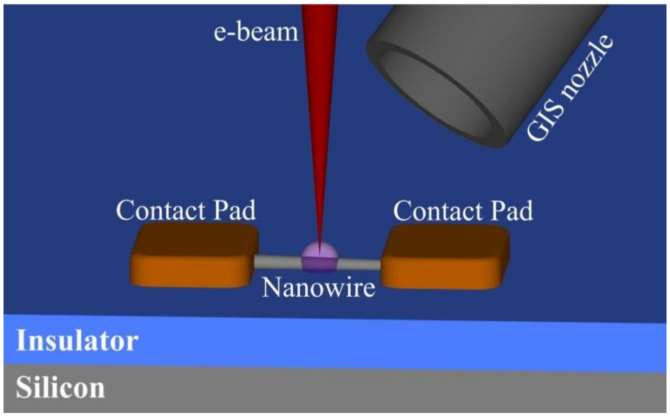

Fig. 1. Concept of custom-tailoring of Si-nanowire by localized processing with a focused electron beam.

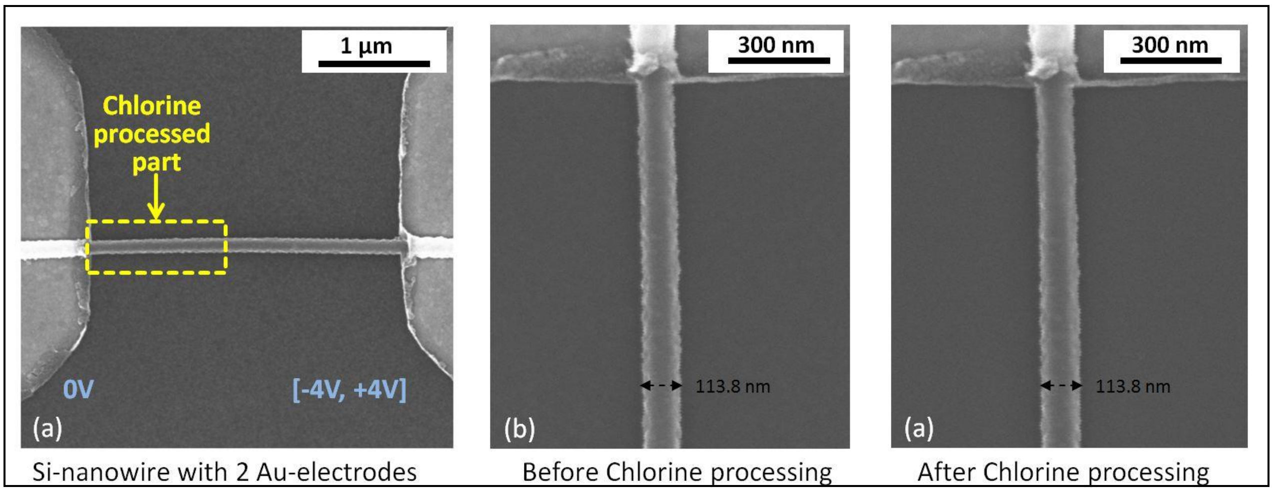

Fig. 2. SEM-images of a Si-nanowire contacted on both sides with sputter deposited gold pads.

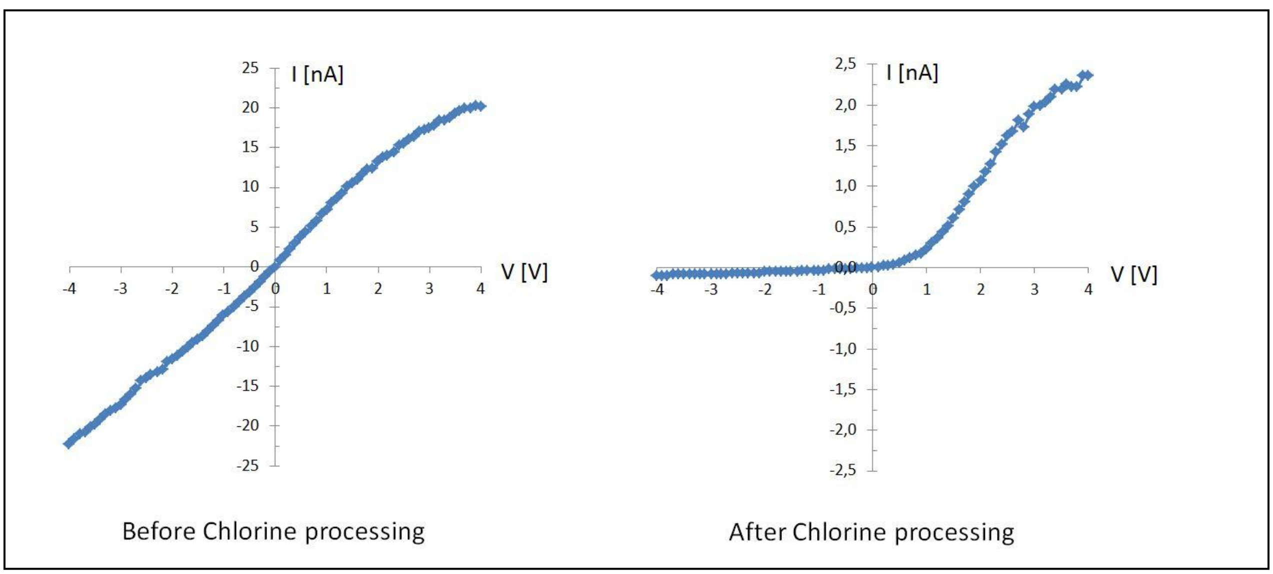

Fig. 3. Electrical I-V measurements of a Si-nanowire before and after the Chlorine processing.