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Contacting of Si/SiO₂ core/shell nanowires using laser photolithography

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Abstract

The contamination results of extended ion or electron beam irradiation, the type of substrate used, the time required to contact a set of nanowires to gain accurate acknowledge on nanowires properties are the main limitations of focused ion beam (FIB) and electron beam lithography (EBL) techniques for nanowires characterization. We present in this latter, a direct writing technique which is laser photolithography to contact a set of core/shell Si/SiO₂ nanowires fabricated by 30 KeV AuSi liquid metal alloy source focused ion beam LMAIS-FIB using Au⁺ ions to allow forward the electrical characterization of these nanowires.

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Keywords: Nanowires, Laser, photolithography, solar cell.

1. Introduction

Silicon nanowires Si (NWs) are one-dimensional structures with a length greater (some micrometers) than the other sizes (some nanometers). The large surface/volume ratio is useful to enhance the performances of electronic nanodevices. Recently, Si NWs are widely used in the next generation of CMOS nanodevices like field effect transistors (FETS) [1], junction less transistors (JLTs) [2] and tunnel effect transistors (TETs) [3]. The little volume of NWs makes it a favorable choice for chemical and bio-sensing [4,5]. Another application of NWs is solar cells, in which these configurations allow to maximize solar spectrum trapping and then increase absorption.

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Moreover, they are decreasing the density of states in surface which leads to decrease the recombination of photogenerated carriers and reduce the distance to collecting junction. Usually, two techniques are used for fabrication of NWs: top-down and bottom-up techniques. The top-down technique uses lithography to define the fabricated structure and then transfer it to the substrate by etching or similar way. In bottom-up approach, the material is added to substrate in self-organized way. Bottom-up uses vapor liquid solid (VLS) method for synthesis the NWs, in this method a metallic nanoparticules are employed to growth the NWs [6]. Recently, FIB/ scanning electron microscopy (SEM) dual beam system is widely used for micro and nanofabrication in machining applications [7]. The main element of FIB is called LMIS that generates the ion beam. The advantage of LMIS-FIB is direct local writing and milling shapes with ultimate sizes due to maskless compared to other techniques such as optical lithography and EBL [8]. Most of LMIS used in laboratories and industry operates with Gallium Ga^+ ions source [9], this type of LMIS gives good resolution and stability thanks of its low melting temperature and volatility [9]. However, it has several drawbacks and adverse effects on surface of the target material (contamination, heavy implementation etc). Liquid Metal Alloy Ion Source (LMAIS) AuSi and AuGe are appearing as alternative sources for lithography to exceed the Ga LMIS limits [10]. Many techniques have been employed for the electrical characterization of NWs such as EBL and FIB. Although each has limitations, such as; the nature of the substrate used, the time required to connect a number of NWs and also the difficulty of locating a single NWs, especially the NWs grown by VLS technique. Laser photolithography is a powerful technique for contacting and characterizing a set of NWs and it is a good candidate to replace EBL [11] and FIB [12]. Their advantages are that is quick, flexible, maskless, direct writing and contacting patterns on arbitrary substrate; and also can avoid any potential contamination associated with extended ion beam or electron beam irradiation. In addition, the clear visibility of NWs through the photoresist. In this work, we report fabrication of SiO_2/Si nanowires on silicon on insulator (SOI) substrate with a width of 450 nm, length of 50 μm and depth of 20 nm using 30 KeV Au^+ of AuSi LMAIS-FIB. Laser photolithography is employed for rapid electrical contacting of the NWs using Aluminum metal.

Nanostructure

NWs	nanowires
FIB	Focused Ion Beam
SiO_2	Silice
LMIS	Liquid Metal Ion Source
VLS	Vapor Liquid Solid
FETS	Field Effect Transistors
JLTs	Junction Less Transistors
CMOS	Complementary Metal Oxide Semiconductor
TETs	Tunnel Effect Transistors
Ga^+	Gallium
Si	Silicon
LMAIS	Liquid Metal Alloy Ion Source
SOI	Silicon On Insulator
SEM	Scanning Electron Microscopy
AFM	Atomic Force Microscopy
UV	ultraviolet
PL	Photoluminescence
EBL	Electron Beam Lithography
RTO	Rapid Thermal Oxydation

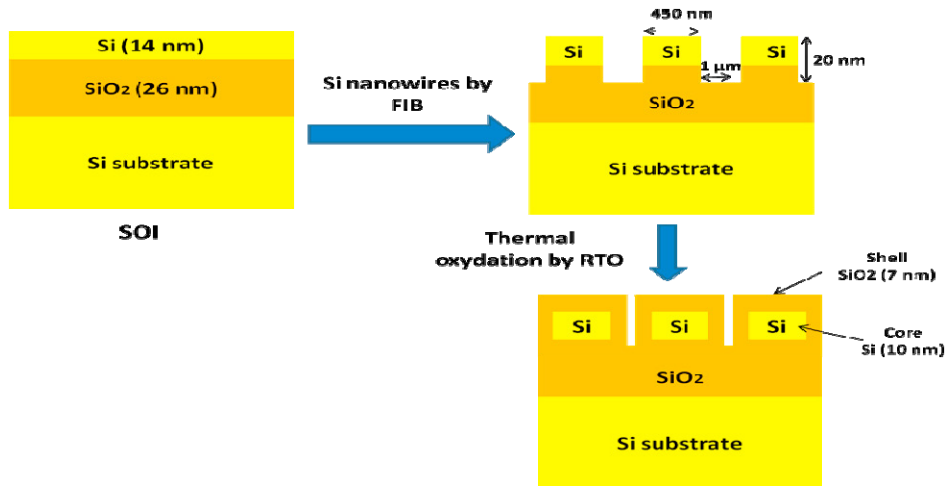


Fig.1. fabrication steps of core/shell Si/SiO₂ nanowires.

2. Sample preparation and metallization

(100) oriented SOI wafer with a Si layer thickness of about 14 nm is used for nanowires fabrication as shown in Fig.1. The sample is cleaned by the Shiraki method to remove the residual impurities present in the SOI. Before starting the creation of nanowires on our sample using AuSi COBRA FIB/SEM dual beam from Orsay Physics, we made steps of calibration to achieve the optimal parameters of patterning by FIB to be employed on our sample. For this, four nanopatterning with different parameters as shown in table 1 have been created. Fig.2 represents the integrated SEM images for the four nanopatterning created by 30 KeV Au⁺ ions. Atomic force microscopy (AFM) PSIA XE-100 is used for characterization, the analysis of the related AFM images (Fig.3 (a)) allowed us to choose the parameters of the pattern “A” to continue thereafter etching our desired nanowires by FIB. Indeed, in this case the etched depths obtained are consistent with those applied for, and also the AFM profile (Fig.3 (b)) shows that NWs contours and profiles are better defined, with a lower roughness. Using parameters of pattern A, we have fabricated a set of nanowires with a width of 450 nm, length of 50 μm and depth of 20 nm approximately by Au⁺ ions of AuSi LMAIS-FIB. Next step is to surround the nanowires by thermal oxide SiO₂ layer using rapid thermal oxidation (RTO) (Fig.1).

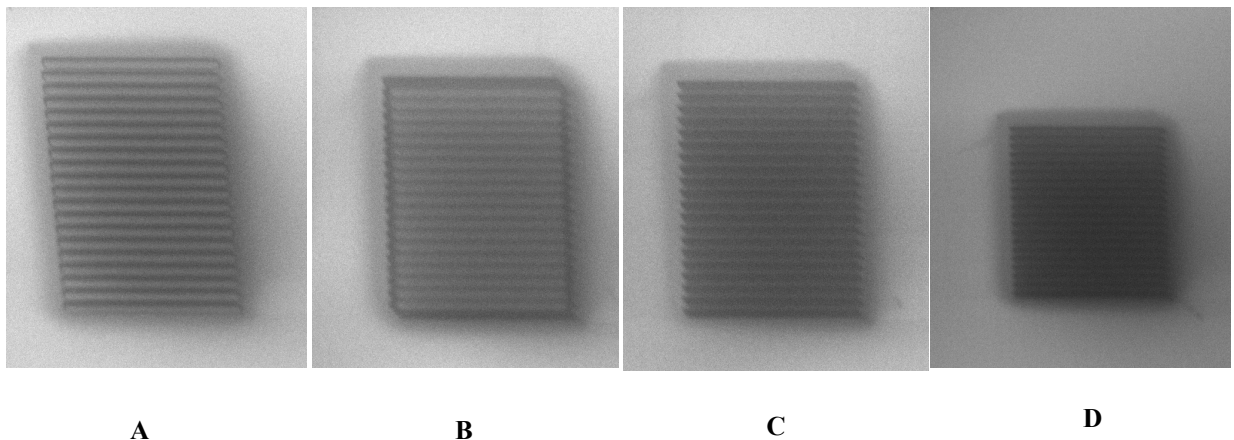


Fig.2. SEM images of the four nanopatterning created by 30 KeV Au⁺ for calibration.

Table 1. The important parameters of milling of the four nanopatterning used for calibration.

Parameter/pattern	A	B	C	D
Probe current (pA)	18.9	18.9	19	19
Milling depth Z(nm)	20	20	70	20
Milling mode	serial	parallel	parallel	parallel
Pattern length (μm)	6	6	6	6
Pattern width (μm)	0.3	0.3	-	-
Distance between two adjacent patterns (μm)	0.3	0.3	0.6	0.5
Shapes	rectangles	rectangles	lines	lines
Time of milling (min)	2.48	2.48	1.29	1.29

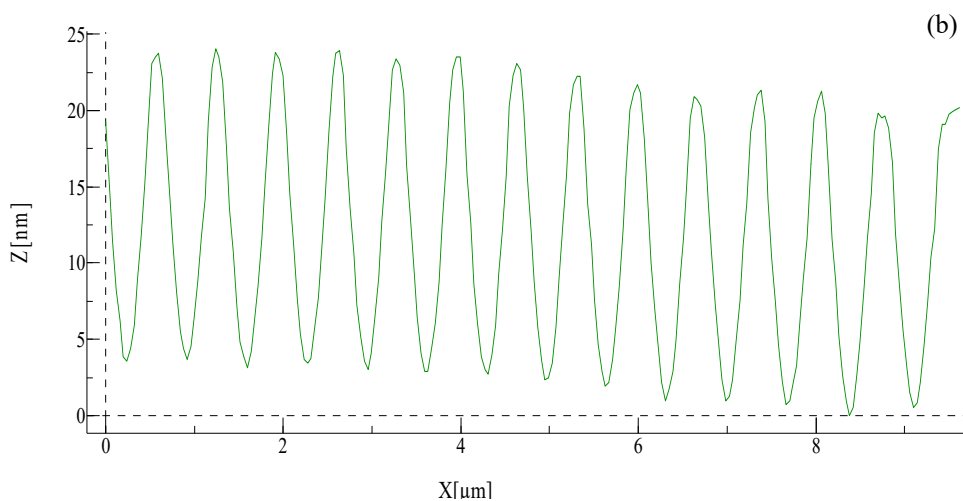
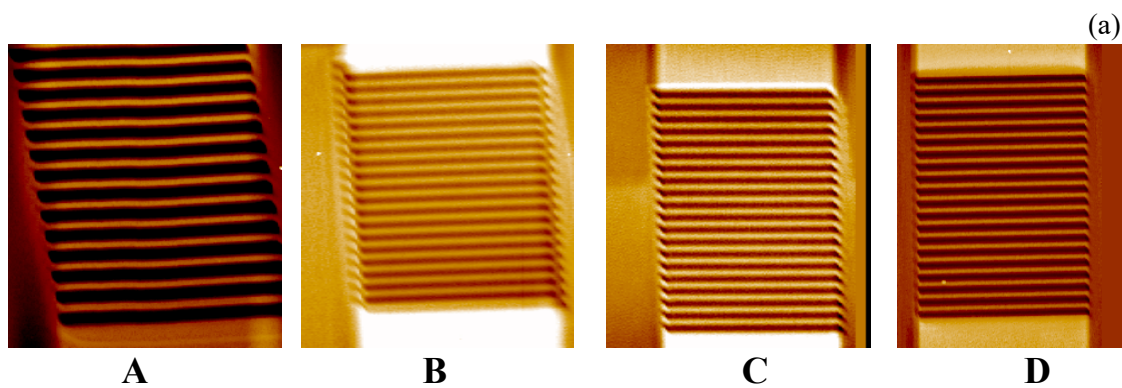


Fig.3. (a) AFM images of the four nanopatterning created by 30 KeV Au^+ for calibration. (b) AFM profile of the nanopatterning "A".

Large contacts (pads) have been created to connect the nanowires produced. For this, we have used laser photolithography machine. The device employed in the laboratory was Dilase 250 (KLOE Company). The device is equipped a laser diode source emitting at 375 nm, with a power of 70 mW. This equipment offers both vectorial and scanning writing modes and ensures a trajectory within a 100 nm maximum deviation range. Two softwares Kloe Design and Dilase Soft are integrated to allow the patterns design and implementation. The Dilase 250 system is compatible with most of the commercially available photoresists. The advantage of laser photolithography is the direct writing on the sample by scanning patterns under laser beam and therefore does not require a mask as in standard optical lithography [13]. This technique is particularly suitable for production of prototypes, where we can realize patterns with a various shapes. The system engraving resolution is $\leq 2 \mu\text{m}$. Firstly, we made several resin deposition to produce patterns of different shapes using Dilase Soft as shown in Fig.4 by changing major process parameters (modulation of the laser power and the write speed) until achieving 2 μm of resolution. The type of resin employed was S1805. We have found that a modulation of 10 and write velocity of 11 $\mu\text{m/s}$ are the best parameters which give excellent resolution. Then, we have utilized these optimal parameters to fabricate our pads. The deposition of Al metal has done using lift-off technique.

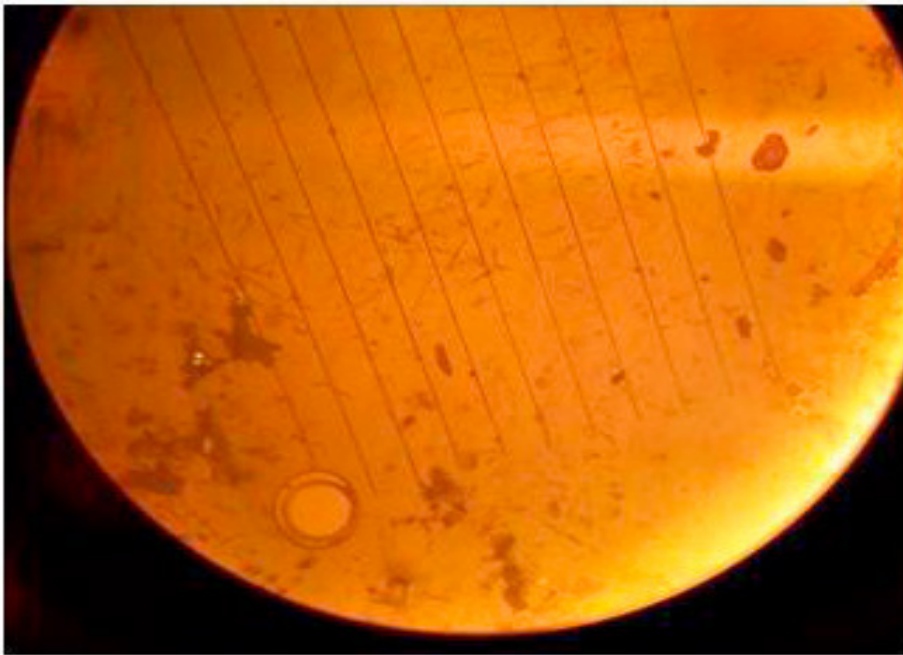


Fig.4. Top-view optical microscope photograph of lines produced by laser lithography for calibration.

3. Results and discussion

The SEM and AFM images of a 20 Si /SiO₂ core/shell NWs with a width of 450 nm produced by 30 KeV Au⁺ LMAIS/FIB are shown in Fig.5 (a) and (b), respectively. It was clear that the NWs produced are well arranged, and their dimensions are effectively checked. Fig.6 (a) exhibits a top-view optical microscope photograph indicating the layout of the resulting Si/SiO₂ NWs contacted by two pads of Aluminum Al using laser photolithography. While Fig.6 (b) represents the AFM images of the contacted zone of NWs with Al pads.

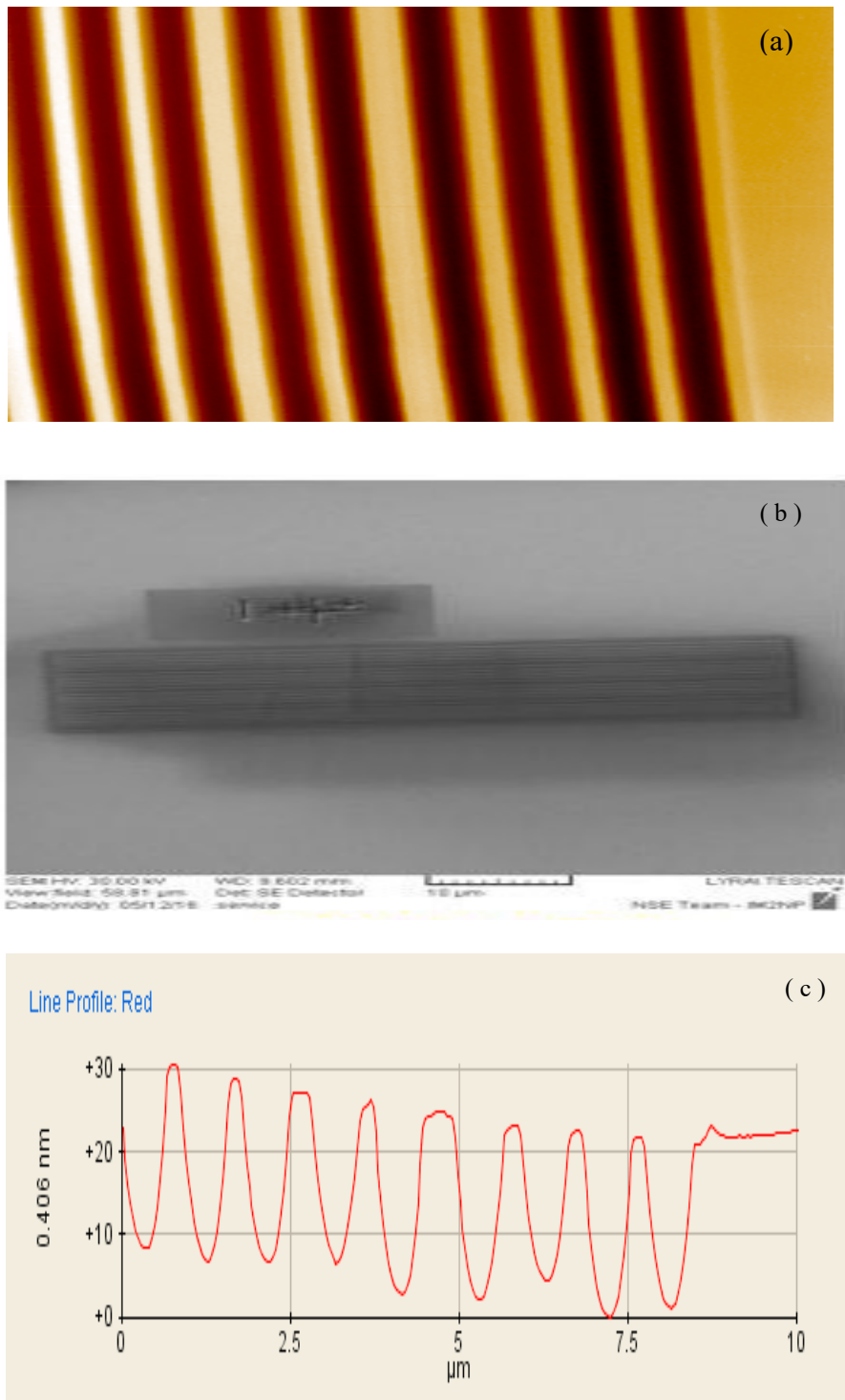


Fig.5. (a) AFM images of 20 Si/SiO₂ core/shell NWs with width of 450 nm created by 30 KeV Au⁺. (b) SEM images of the correspondent NWs. (c) AFM profile

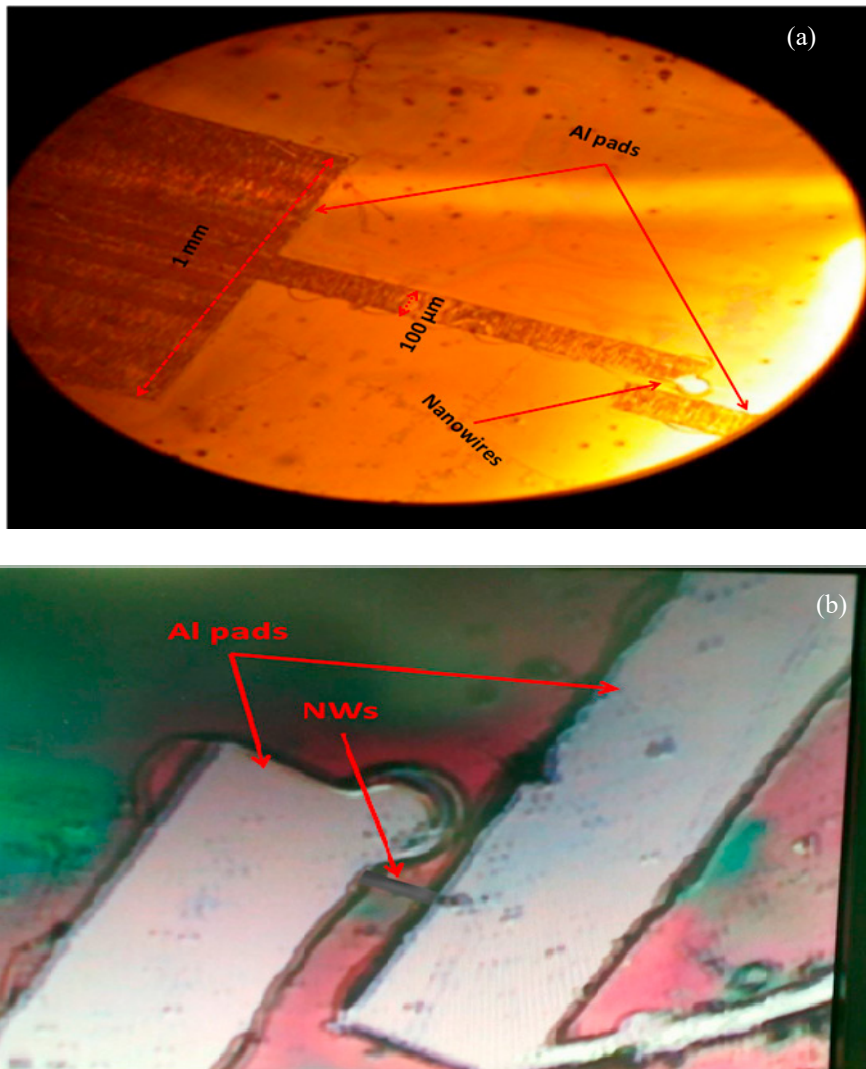


Fig.6. (a) Top view optical microscope of contacted NWs by Al pads (b) AFM images of contacted zone of NWs with Al pads.

4. Conclusion

Core/shell Si/SiO₂ NWs with width of 450, a length of 50 μm and a depth of 20 nm were produced by 30 KeV Au⁺ ions of AuSi LMAIS/FIB in this work. These NWs have been contacted by Al pads using laser photolithography. Several experiences have been done in goal to get optimal parameters of milling by FIB and to achieve the best process parameters for laser photolithography. We have found that a modulation of laser power of about 10 and write speed of 11 μm/s give optimal resolution for creation Al pads to contact the NWs by laser photolithography. Finally, we are looking to complete this work by extracting the electrical I-V characteristics and photoluminescence (PL) spectra of the produced NWs for photovoltaic applications.

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