

Fabrication of Metal Nanobridge Arrays using Sacrificial Silicon Nanowire

Kook-Nyung Lee[†], Kyounggun Lee*, Suk-Won Jung*, Min-Ho Lee* and Woo-Kyeong Seong*

Abstract – Novel fabrication method of nanobridge array of various materials was proposed using suspended silicon nanowire array as a sacrificial template structure. Nanobridges of various materials can be simply fabricated by direct deposition with thermal evaporation on the top of prefabricated suspended silicon nanobridge arrays, which are used as a sacrificial structure. Since silicon nanowire can be easily removed by selective dry etching, nanobridge arrays of an intended material are finally obtained. In this paper, metal nanobridges of Ti/Au, around 50–200 nm in thickness and width, 5–20 μm in length were fabricated to prove the advantages of the proposed nanowire or nanobridge fabrication method. The nanobridges of Ti/Au after complete removal of sacrificial silicon nanowire template were well-established and bending of nanobridge caused by the tensile stress was observed after silicon removing. Up to 50 nm and 10 μm of silicon nanowire in diameter and length respectively was also very useful for nanowire templates.

Keywords: Metal nanobridge array, Suspended nanowires, Sacrificial silicon nanowires, XeF_2 dry etching, Nitride nanobridge

1. Introduction

Nanowires (NWs) have been researched extensively due to their promising electrical properties based on one-dimensional quantum confinement effects and potential for nano integration. [1–3] Various kinds of technology to fabricate the NWs and assemble them into devices have been developed to realize their full potential in applications. [4–6] The conventional bottom-up approaches to fabricate NWs require complicated assembly procedures limited by high alignment accuracy owing to nano-scale wire size. To overcoming these problems, we previously proposed alternative approach to fabricate silicon nanowire (SiNW) arrays which combines top-down based micro-machining technology with transfer-printing of SiNWs to a device substrate. But the materials for NWs were limited to be single crystalline silicon in our previous approach. Recently, fabrication of metal NWs have been researched extensively because of its future applications such as nano-resonator, nano-scale sensors, and field emission displays (FED). [7–9] Most of metal NW fabrication methods utilize nano template and conformal deposition of target material to filling on it such as a bundle of carbon-nanotube (CNT), anodized aluminum oxide (AAO) template, polycarbonate membranes, polyvinyl alcohol nanofiber and so on. Mass production of nanotube/nanowire shape structures are obtained after sacrificial template material was removed selectively. However, position-controlled, well-ordered,

parallel aligned to the substrate of nanowire were hard to obtain, which is actually required for nanowire application devices such as sensors, electronics, and nano mechanical resonators. In this communication, we report novel method to fabricate well-ordered, horizontal aligned, and suspended metal nanobridge arrays by applying suspended silicon nanowire arrays for sacrificial template structure. Metal deposition process with evaporators was performed on top of the sacrificial silicon nanobridge templates. Any materials which can be deposited directionally to the nanobridge template substrate are able to be applied to this fabrication method.

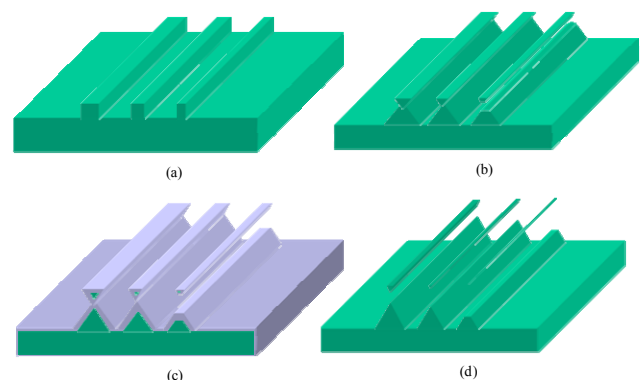


Fig. 1. Fabrication process of freestanding SiNW arrays: (a) Si anisotropic dry etching by deep reactive ion etching; (b) Si anisotropic wet etching by TMAH; (c) Thermal oxidation for thinning nanowire; (d) Releasing suspended SiNW arrays by SiO_2 removing.

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2. Experiment

Our metal nanobridge arrays are simply fabricated by several steps of micromachining technology. The fabrication process starts with manufacturing freestanding SiNW arrays for a sacrificial template structure for the metal nanobridges. Since materials we would like to fabricate as a nanobridge would be deposited on top of the prefabricated SiNW bridge array, the inverted-triangular shape in cross-section of sacrificial freestanding silicon nanowire structure is favorable to be used for nanobridge templates. The fabrication process of silicon nanowire bridge for the template is straightforward. [10, 11].

Fig. 1 briefly shows the fabrication process of freestanding SiNW arrays which is a template for nanobridges of other materials. Firstly, photolithography and reactive-ion-etching (RIE) of silicon produce the silicon columns. Anisotropic wet etching of silicon columns using tetramethylammonium hydroxide (TMAH) is performed to produce hour-glass shaped silicon columns which are surrounded by (111) planes of silicon (Fig. 1(a), (b)). In order to obtain suspended silicon lines with nano width, the hour-glass shaped silicon columns need to be thermally oxidized and thinned to produce around or below 100 nm in width or diameter of 'nano'wire (Fig. 1(c)). With removal of the silicon dioxide using HF based solution such as buffered oxide etcher (BOE), the freestanding silicon nanowire bridges are finally obtained.

Fig. 2 shows the fabrication process flow of metal nanobridge arrays using silicon nanowire template. Directional deposition of intended materials such as thermally evaporated metals on top of sacrificial SiNW array template can provide simple fabrication of metal nanobridge arrays. Only top side of inverted-triangular shape suspended silicon nanowires is deposited by target materials because of directional deposition of those materials to the SiNW arrays substrate (Fig. 2(a), (b)). The sacrificial SiNW arrays template is removed by isotropic

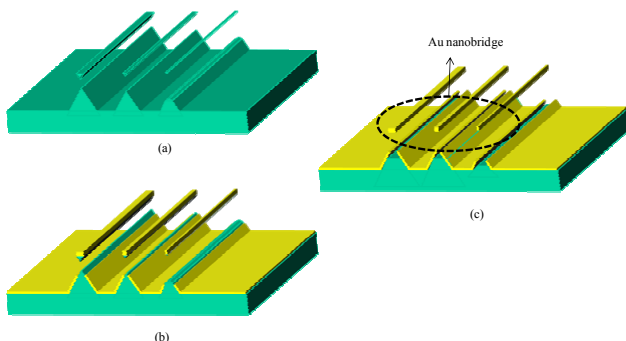


Fig. 2. Fabrication process of metal nanobridges using freestanding SiNWs: (a) Pre-fabricated SiNW arrays; (b) Evaporation or deposition of target materials (Ti/Au in this communication) on top of suspended SiNWs; (c) Removing sacrificial silicon nanowire to free metal nanobridges.

XeF₂ etching as shown in Fig. 2(c). Finally, nanobridge arrays of target material are obtained. In our approach to obtain nanobridge array of various material using suspended silicon nanowire template, the position, pitch, array density, length and width of nanobridge can be precisely controlled by photolithography mask. Various metals deposited with thermal evaporation process can be simply adopted to this fabrication method.

We applied Ti/Au as nanobridge material to verify the proposed fabrication method. Ti was used for interlayer for the improvement of Au adhesion. Various width of the suspended silicon nanowire in range of 50 ~ 300 nm can be fabricated for sacrificial structure. [10] The dimension of Au nanobridge depends on the silicon template so that it is determined by the deposition thickness of metal evaporation and the width of sacrificial silicon nanowire.

Fig. 3(a) and (b) show the SEM figures of fabrication results for the comparison of before and after Au evaporation on top of silicon nanowire template, respectively. Ti/Au was deposited around 100/600 Å in a thickness by thermal evaporation. Silicon nanowire around 50 nm and 10 μm in a width and length, respectively, was also useful for the template. Note that the diameters (or width) of nanobridge gets thicker after Au deposition. We can see the layers boundary of deposited Ti/Au and silicon nanowire in the enlarged view of nanowire as shown in Fig. 3(c). Besides, we can make sure that there are tensile stress caused by deposited Ti/Au layer on top of silicon nanobridge from the crack occurred at the both ends of silicon nanowire bridges as shown in Fig. 3(d), which is the result of that deposited Ti/Au thickness is around 800/1200 Å. Regardless of the stress caused by Ti/Au layer, Ti/Au nanobridges were well fabricated just by controlling the deposition thickness of Ti/Au.

Fig. 4 shows the SEM figures of the fabrication results of Au nanobridge after complete removal of silicon nanowire template. Silicon was removed in 3000 mTorr pressure of pure XeF₂ chamber for 30 sec just after Au nanowire deposition. We can make sure that silicon was removed completely through the comparison of Fig. 3(d) and Fig. 4(a), which are the same specimen. In Fig. 4(b) and (c) Ti/Au nanobridges were well obtained by complete and excessive removal of silicon by XeF₂ dry etching. Silicon under the deposited Ti/Au layer was removed by enough etching of silicon and observed clearly through the dark-colored cavity especially near the posts at the ends of nanobridges. Silicon sacrificial nanowire was 200 nm and 20 μm in a diameter and length respectively. The deposition thickness of Ti/Au was around 10/60 nm. Therefore, ribbon-like Ti/Au nanobridges, which are 200 nm, 70 nm and 20 μm in a width, thickness and length, respectively, were also well-established after complete removal of silicon templates. Bending caused by tensile stress from the Ti/Au deposition on top of silicon nanobridge was also observed.

Fig. 4(d) shows low-stress Si₃N₄ deposited silicon

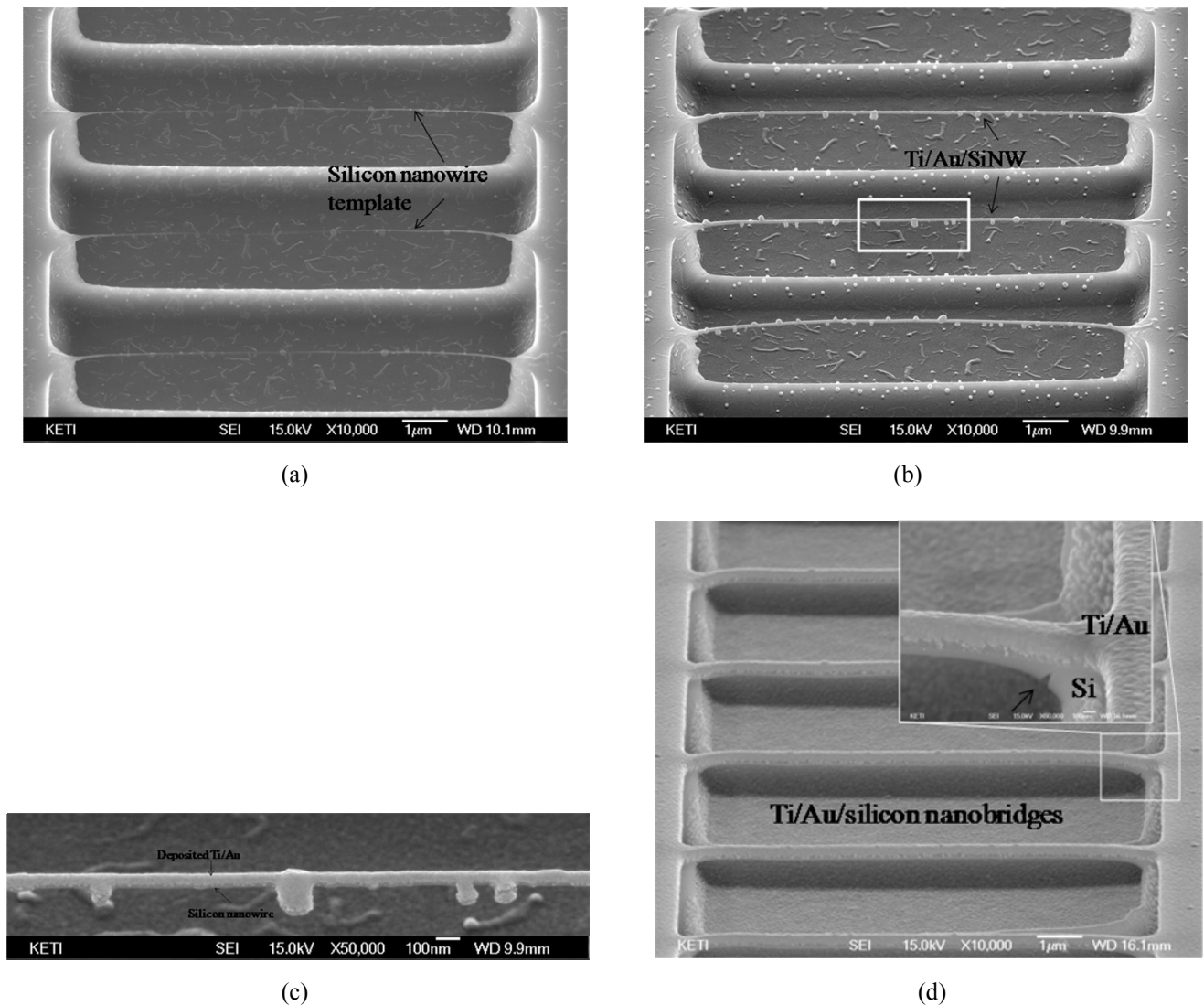


Fig. 3. SEM figures of Ti/Au deposited nanobridges on top of silicon nanowires: (a) SEM figure of silicon nanowire template before metal deposition; silicon nanowire is around 50 nm and 10 μ m in diameter and length respectively; (b) SEM figures of nanowire bridge array after Ti/Au evaporation; Ti/Au was deposited around 100/600 \AA in a thickness with thermal evaporation; (c) Enlarged view of Ti/Au deposited nanobridge on top of silicon nanowire template; boxed area in Figure (b); (d) Ti/Au/silicon nanobridge array, Ti/Au was deposited 800/1200 \AA on top of 200 nm diameter silicon nanowire; note that the crack was occurred at the both ends of silicon nanobridge as arrow indicated.

nanobridges in a thickness of 100 nm with a low pressure chemical vapor deposition (LPCVD) process. Silicon nanowire for template was around 200 nm and 100 μ m in a diameter and length. Note that there is no observed severe bending caused by thin film deposition stress as we expected in this conformal deposition of Si₃N₄ onto the silicon nanobridge.

As shown in Fig. 4(a) to (c), the freestanding Au nanobridges are successfully fabricated. Our fabrication strategy using silicon nanowire sacrificial template allows the Au nanobridges to be well-ordered horizontally on the intended position of a substrate. The fabricated Au nanobridge arrays are horizontally-aligned to the substrate

and both ends of the nanobridge are connected to the posts. This geometry of the Ti/Au nanobridges allows easy electrical connecting for electrical characterizations or other applications. With similar structure, we have already showed high temperature operating micro heater which has Ti/Pt heat resistor deposited on the insulated suspended silicon filaments. [12]

3. Conclusion

In conclusion, we propose novel fabrication process for metal nanobridge arrays and successfully fabricate Au

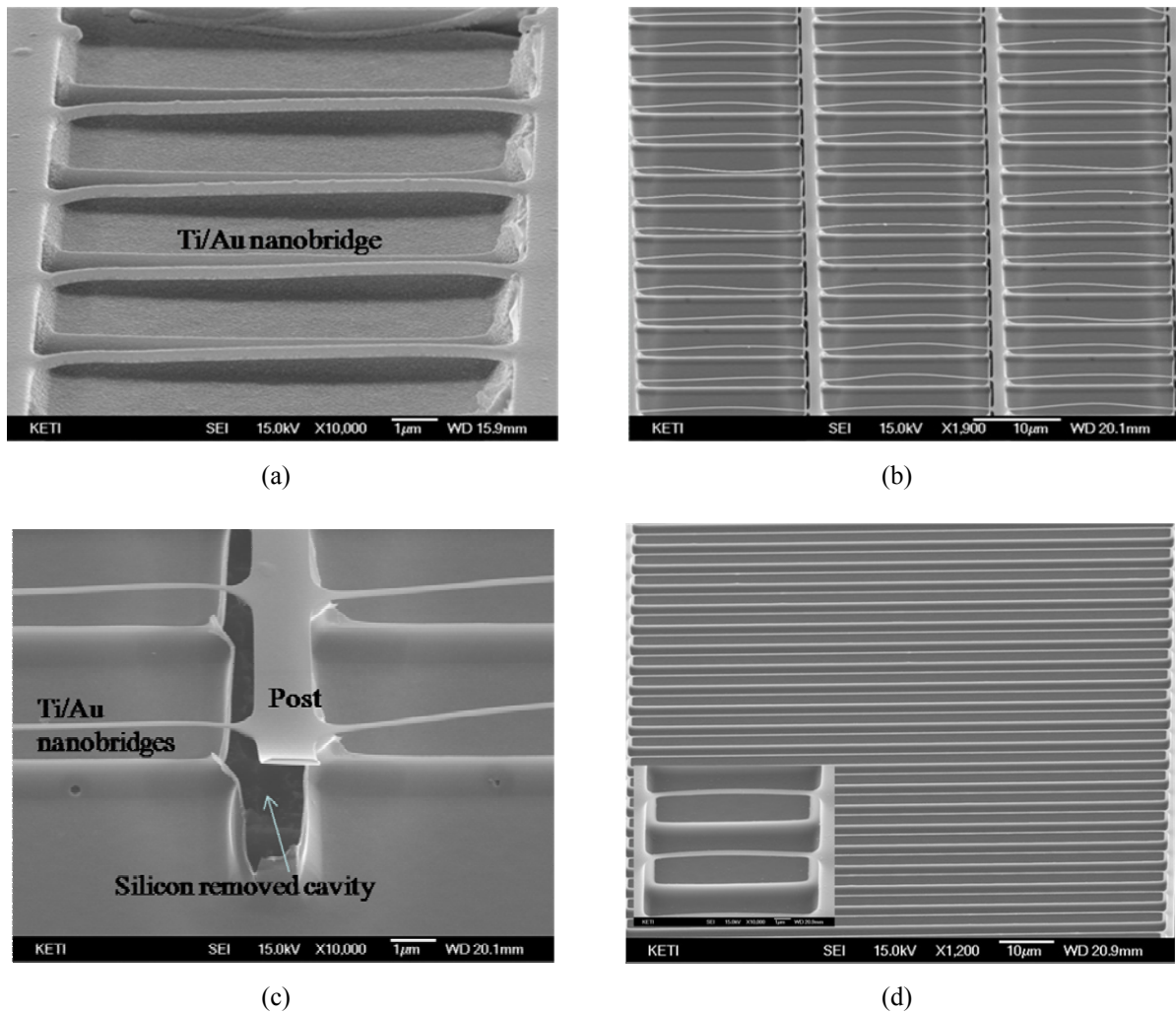


Fig. 4. Fabrication results of nanobridge array of various materials: (a) Ti/Au nanobridge after removing silicon nanowire template; Ti/Au nanobridge is 10 μm in length and 800/1200 \AA in a width. Sacrificial silicon was around 200 nm in diameter; (b) Suspended Ti/Au nanobridge array after removing sacrificial silicon nanowire template, Ti/Au nanobridges are 20 μm , around 200 nm, and 70 nm in length, width, and thickness respectively; note that Ti/Au nanobridges were bended after silicon removal by tensile stress. Black colored cavity near the posts is observed by the silicon template removal; (c) Enlarged view of post area to make sure the removal of silicon nanowire template; (d) LPCVD Si₃N₄ nanobridge with silicon nanowire core; low stress Si₃N₄ was deposited 1000 \AA thickness in 200 nm silicon nanowire bridge in diameter. The length of nanobridge is 100 μm and 10 μm in the figure and the inset, respectively.

nanobridge arrays which have 50 ~ 200 nm in width and around 50 nm in thickness. The suspended SiNW arrays are employed as a sacrificial structure like nano-template. Any materials which are able to be deposited anisotropically can be applied to this fabrication method. The presented fabrication method has advantages of precise positioning and horizontal structure. Moreover, benefiting from conformality of material deposition technologies including chemical-vapor-deposition (CVD) and atomic layer deposition (ALD), nano-shell structure of various materials with a triangular silicon core would be easily obtained as LPCVD Si₃N₄ deposition shown in Fig. 4(d). By the presented fabrication methods, the metal

nanobridge arrays can be applied future applications such as nanomechanical resonator, tools for studying mechanical properties of materials, which is our on-going study.

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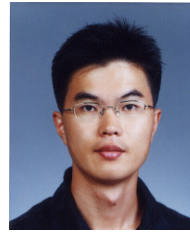
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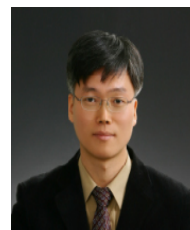
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