

Fabrication of a nano-scale gap by selective chemical deposition

Lan Huang,* Lina Xu, Haiqin Zhang and Ning Gu

National Laboratory of Molecular and Biomolecular Electronics, Southeast University, Nanjing 210096, People's Republic of China. Tel: +86 25 3794960; Fax: +86 25 3619983; E-mail: huanglan822@yahoo.com

Received (in Cambridge, UK) 19th October 2001, Accepted 29th November 2001
First published as an Advance Article on the web 21st December 2001

An electrode nanogap of 45 nm has been prepared by a new method in which the initial gap of 1–2 μm obtained by conventional lithography was shortened by selective chemical deposition of copper onto the electrodes.

In recent years, fabrication of patterns on the nano-scale level, such as nanowires and nanogaps, has been drawing a great interest in the scientific community not only due to the need for ever-increasing miniaturization of microelectronics, but also because of the discovery of many novel phenomena that occur on the nano-scale. Compared with the other patterns, nano-scale gaps are more crucial to successfully make a nanodevice, such as nano-transistors or single electron tunneling junctions. However, the gaps prepared by conventional lithography are on micro-scale and can not reach the nanometer level to meet the needs of fabricating nanodevices. In order to solve this problem, researchers have recently proposed many new methods, including electron beam lithography,¹ carbon nanotube masking,² and electrodeposition,³ which have been proved to be successful in fabricating nanogaps. However, the sophistication, high cost and low yield of those methods limit their wide application. In this communication, we present a very simple and economical method to produce nanogaps by selective chemical deposition of copper onto gold electrode pairs separated at the microscale level.

First, gold electrode pairs are prepared by conventional lithography with 1–2 μm gaps. In this stage, the gap between electrodes is not critical. Two self-assembled monolayers (SAMs) materials are patterned on the gold electrodes and Si substrate, respectively. Then, the gaps at the micro-scale level between the electrodes can be shortened to the nano-scale by selective chemical deposition of copper on the electrodes.

Fig. 1 shows the procedure of the patterning process of chemical deposition. The two SAMs were both prepared by the

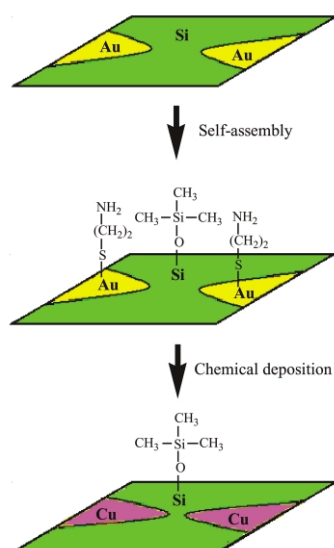


Fig. 1 Schematic representation of selective chemical deposition of copper on gold electrode pairs to obtain nanogaps.

wet process.⁴ The first SAM was prepared by immersing the electrodes into an ethanol solution containing 1×10^{-4} mol L^{-1} 2-mercaptoethylamine [$\text{NH}_2(\text{CH}_2)_2\text{SH}$] for 6 h at room temperature, followed by rinsing with ethanol for 3 min. $\text{NH}_2(\text{CH}_2)_2\text{S}$ films were formed by thiol groups ($-\text{SH}$) spontaneously adsorbing on the Au surface with Au–S covalent bonding,⁵ with pendant $-\text{NH}_2$ groups pointing outwards. H_2N groups provided the active site for attaching the catalyst in the following process. To form the second SAM, the substrate was dipped into an ethanol solution containing 1×10^{-3} mol L^{-1} of chlorotrimethylsilane (TMS) at room temperature for 12 h, and then rinsed with ethanol and deionized water in turn for 2 and 1 min, respectively. In this manner, the surface of the Si substrate was changed from hydrophilic into hydrophobic ($-\text{Si}(\text{CH}_3)_3$), which could minimize the physical absorption of the Pd catalyst.

Next, metallic copper deposition on the top of the existing pattern was performed *via* the electroless plating technique, in which Pd as the catalyst induced the redox reaction in the electroless plating solution. The SAMs modified electrode was dipped into an activator solution, containing mainly PdCl_2 for 10 min. After rinsing by water, the selectively activated electrode was introduced in the chemical plating solution, containing 13 g L^{-1} $\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$, 29 g L^{-1} potassium sodium tartrate, 12 g L^{-1} sodium hydroxide and 95 ml L^{-1} formaldehyde, at 28 $^\circ\text{C}$ for 5 min. Finally, the electrode was ultrasonically cleaned for 1 min to wipe off the copper physically absorbing in the exposed regions, and rinsed with deionized water for 2 min. Pd, as the nuclei of chemical deposition, was only chemically adsorbed on the gold electrodes by amino groups, and not on the substrate.² In this manner a catalyst pattern was formed. Subsequently, Cu can be selectively deposited on Pd patterned on the gold electrodes. At each tip of the gold electrode pairs, deposited Cu can extend onwards to the center from both sides. As a result, the separation between electrodes can be shortened to the nano-scale.

Fig. 2 shows atomic force microscope (AFM) images of gold electrode pairs fabricated by this technique. As can be seen, the initial separation between the gold electrode pairs was about 1.7 μm . Shortened by the selective chemical deposition, this distance was reduced to *ca.* 45 nm and the resulting three-dimensional image is also shown. The result of an 'elemental analysis test' confirmed that in the tip and the peripheral area of the electrodes there is only metallic copper, without any other metallic impurity.

In conclusion, a novel method has been developed for fabrication of nano-scale gaps, which is rather simple, inexpensive and advantageous. It requires only a relatively short fabrication time, a small instrumental input and can be operated in batches and so this process may be applied in the micro-electronical industry.

We gratefully acknowledge the support to this research from the National Nature Science Foundation of China (No.69890220), the New NSFC project (No.60171005) and Promotional Foundation of Ministry of Education of China for Excellent Youth Teachers (2000).

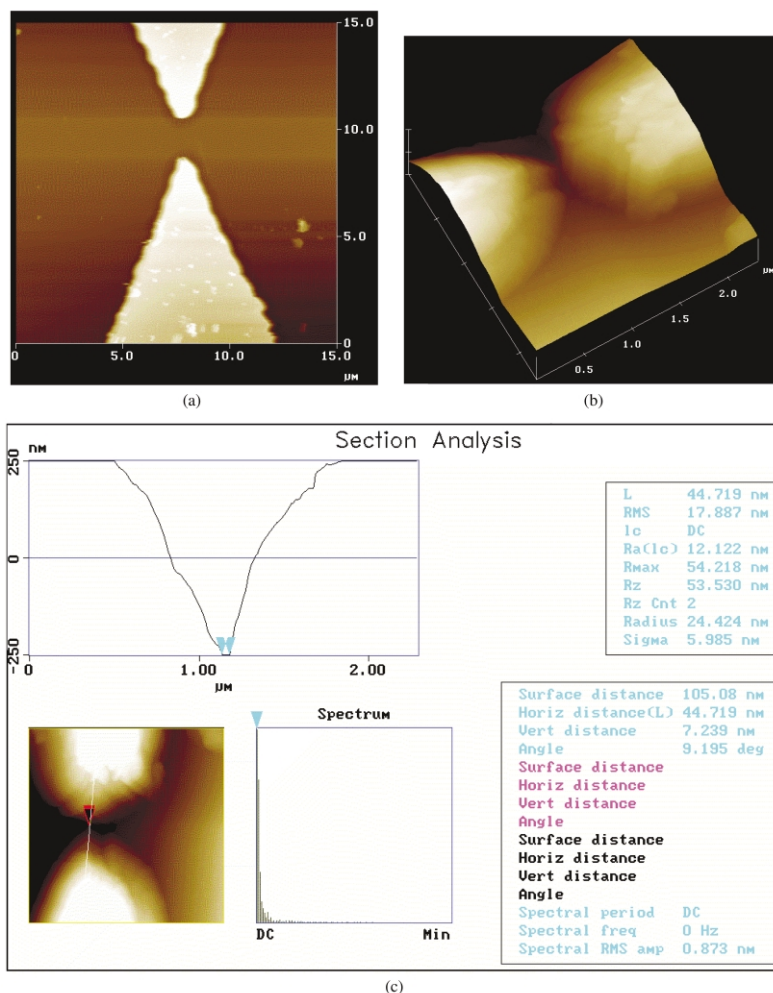


Fig. 2 AFM images of gold electrode pairs before and after selective chemical deposition. (a) Electrode pairs with a 1.7 μm gap before selective chemical deposition. (b) The three-dimensional images of electrode pairs whose gap was shortened to 45 nm by selective chemical deposition. (c) Section analysis of the modified electrodes.

Notes and references

- 1 T. Sato, H. Ahmed, D. Brown and B. F. H. Johnson, *J. Appl. Phys.*, 1997, **82**, 696.
- 2 J. Lefebvre, M. Radosavljevic and A. T. Johnson, *Appl. Phys. Lett.*, 2000, **76**, 3828.
- 3 A. F. Morpurgo, C. M. Marcus and D. B. Robinson, *Appl. Phys. Lett.*, 1999, **74**, 2084.
- 4 M. Ishida, M. Kasuga, T. Kaneko and T. Shimoda, *Jpn. J. Appl. Phys.*, 2000, **39**, 227.
- 5 J. Liu, L. Zhang, N. Gu, J. Ren, Y. Wu, Z. Lu, P. Mao and D. Chen, *Thin Solid Films*, 1998, **327–329**, 176.