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Factors for the Electric Field-Directed Assembly of Gold Nanowires from an Electrolysis Process

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Abstract

Gold nanowires have been fabricated between two Pt electrodes by applying sinusoidal signal voltage and DC offset from an electrolysis process. Factors for the growth and morphology of the nanowires include the frequency and magnitude of AC and DC offset, growing time, and distance between the electrodes.

Key words: Gold nanowires, Electrode, Electrolysis Process.

1. Introduction

Research on fabricating nanowires has attracted a great deal of attention due to the potential applications of nanowires in electronic devices and mechanical devices in the field of nanotechnology. Nanowires made of a variety of materials have been presented. Among them, gold nanowire is of great interest due to its low resistivity, inertness, and biocompatibility. A variety of fabrication techniques have been reported in the past years. These techniques include electrodeposition of materials into templates [1-5], such as anodic aluminum oxide (AAO), self-assembled nanowires[6], dielectrophoresis [7-10], channels patterned by lithography [11], electrolysis [12-15] etc. Among these methods, electrolysis process is one of the most facile approaches to fabricate a single nanowire or a nanowire array between different electrodes [12-15]. Factors to control the growth of the nanowire, however, are not studied. In this work, we report factors that affect the growth and morphology of the nanowires from an ionic solution of gold acetate using an electrolysis process. These factors include the magnitude of AC and DC voltage, the frequency of AC, the growing time, and the distance between electrodes.

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2. Experimental

In our experiments, two parallel platinum electrodes with different gap distances were patterned using a standard UV lithography and lift-off technique. A 10-nm-thick of chromium was sputtered on a SiO_2/Si wafer, following with two platinum pads with a thickness of 150 nm. Six samples with various distances between the two pads were fabricated. These distances include 60 µm, 80 µm, 100 µm, 120 µm and 1 mm. **Figure 1** shows the schematic diagram of the fabricated device used in the experiments. Parallel electric field will form between the electrodes, which will exert a force to move the charged particles, when a voltage is applied.

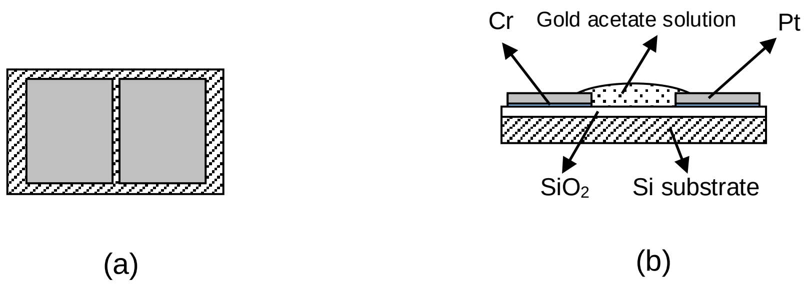

Figure 1. Schematic diagram of the device in our experiments. The Pt electrodes were fabricated on a Si wafer covered by a 300-nm-thick SiO_2. (a) Top view (b) Side view.

In these experiments, a drop of a gold acetate solution was loaded on the top of the two electrodes. A 15 MHz Function/Arbitrary waveform generator (HP 33120A, USA) was used as a source of sinusoidal waves in the frequency 100 µHz to 15 MHz. The max output AC and DC offset voltage are 10 V_{pp} (peak to peak voltage) and 5 V, respectively. A microscope (Labophot-2, Nikon) equipped with a digital camera (Leica DFC 490, Leica Microsystems, German) was used to record the nanowire growing process. After the formation of the nanowires, the silicon plate was rinsed with water to remove the remaining gold acetate solution.

3. Results and Discussion

In these experiments, the growth of gold nanowires was observed once a voltage was applied between the two electrodes as seen in Figure 2. The growth of the nanowires was directed by the electric field and perpendicular to the edges of both electrodes. Fine gold nanowires were observed and the smallest diameter is about 26 nm as seen in Figure 2. The gold component of the nanowires was confirmed by energy dispersive spectrometry (EDS) analysis (Figure 3). It is noted that the peaks of Si, O, and Pt were from the SiO_2 background and the Platinum electrodes. The area of the gold nanowires was rather small comparing to the background, which explains the low intensity of Au peak (Figure 3) compared to those of Si, O, and Pt.

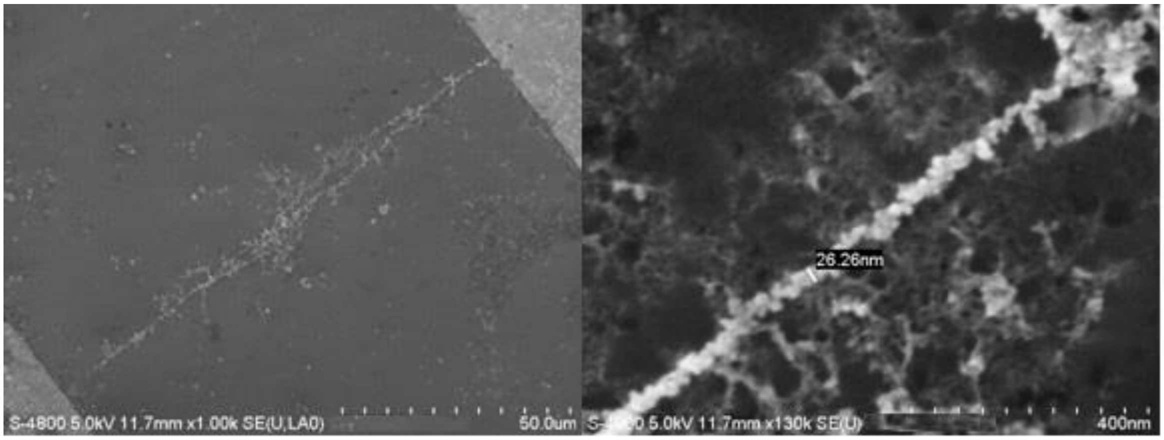

Figure 2. SEM image of gold nanowires fabricated between electrodes with a 120 μm gap space under an applied 6 V_{pp} AC and 200 kHz, and 1 V DC offset. A 0.5 mM gold acetate solution was applied.

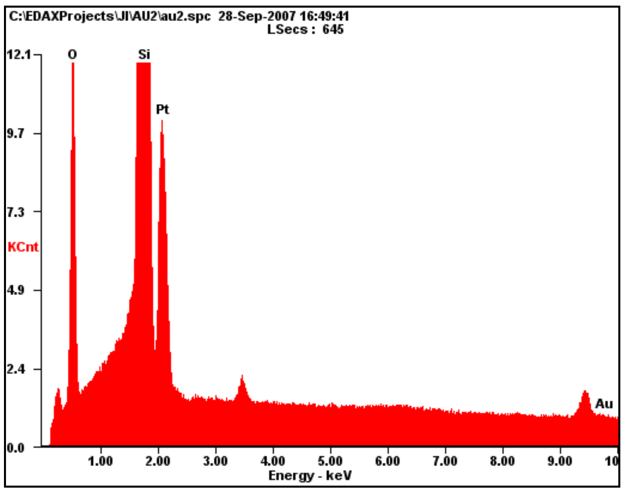

Figure 3. EDS analysis of the gold nanowires on the SiO_2 surface with platinum electrodes depicted in Figure 2.

The growth and morphology of the gold nanowires were affected by the output of function generator, growth time, and the gap distance between the electrodes, which are discussed in the following.

3.1. Effects of the Output of the Function Generator

The formation of nanowires started when appropriate AC was applied, but no nanowires were found with DC only. The nanowires would also grow if an AC and a DC offset were applied between the two electrodes. However, bubbles were observed on the electrodes if the DC was higher than 3 V, showing that the electrodes were etched, so higher DC offset should be avoided. In these experiments, no wires were observed at low frequencies. Nanowires began to form and bridge between the two electrodes when the frequency was higher than 200 kHz (Figure 2). However, at higher frequencies, the nanowires began to form branches or network. 200 KHz seems an optimized frequency to prepare fine and straight gold nanowires.

3.2. Effects of Growing Time

The formation of the nanowires was within seconds and time is critical for the formation of a nanowire or a nanowire array. Figure 4 shows the effect of the growing time on the morphology and structures of gold nanowires. When a nanowire was formed between the two electrodes in 0.5 s, the wire was narrow and appeared straight (Figure 4A). After a longer time such as 5 s, multiple nanowires were formed and bridged between the electrodes. These nanowires were wider and grew to branches (Figure 4B). The results suggest that, the growing time could control the density and structures of the nanowires bridged between the two electrodes. If the formation of a single bridged nanowire is required, the voltage between the two electrodes should be turned off once a single nanowire is bridged between the electrodes, and vice versa.

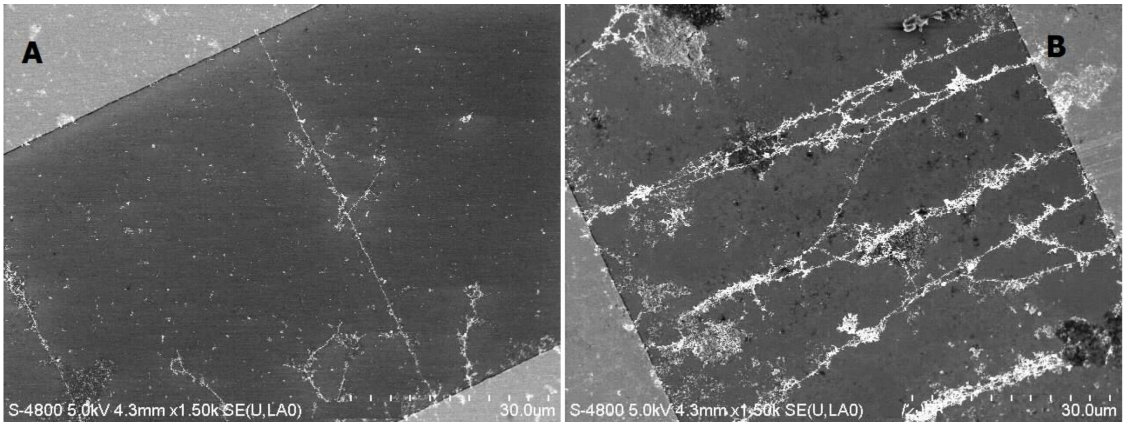

Figure 4. Effect of growing time on the density and structure of gold nanowires. These nanowires grew under an 8 V_{pp} AC at 200 kHz. The gold acetate concentration was 0.5 mM. Left: 60 µm gap, 0.5 s. Right: 70µm, 5 s.

Figure 5 shows how the nanowires grew under 7V_{pp} AC. Black particles was observed floating in the solution once an electric filed was applied. The particles were anchored on the electrodes in 1 s. Three bridged nanowires between the electrodes were observed within 2.4s.

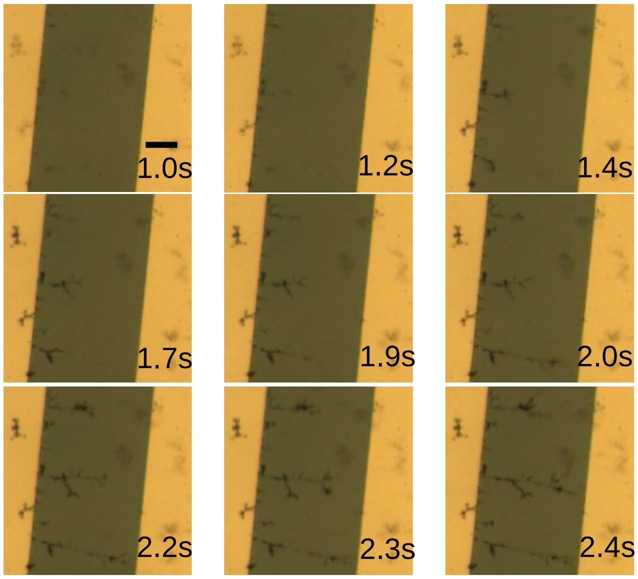

Figure 5. Optical images of the growing process of gold nanowires between electrodes with a 100 µm gap space under 7V_{pp} AC at 200 kHz and 1.5 V DC offset. A 0.5 mM gold acetate solution was deposited on the gap. The scale bar represents 20 µm.

3.3. Effects of Gaps between the Electrodes

A variety of gap distances have been used in our experiments, which include 60 μm, 80 μm, 100 μm, 120 μm. Nanowires were observed in all these experiments without any significant differences. The nanowires can form and bridge the electrodes at a 1 mm gap (Figure 6). However, these wires are wider and appeared in dendritic shapes.

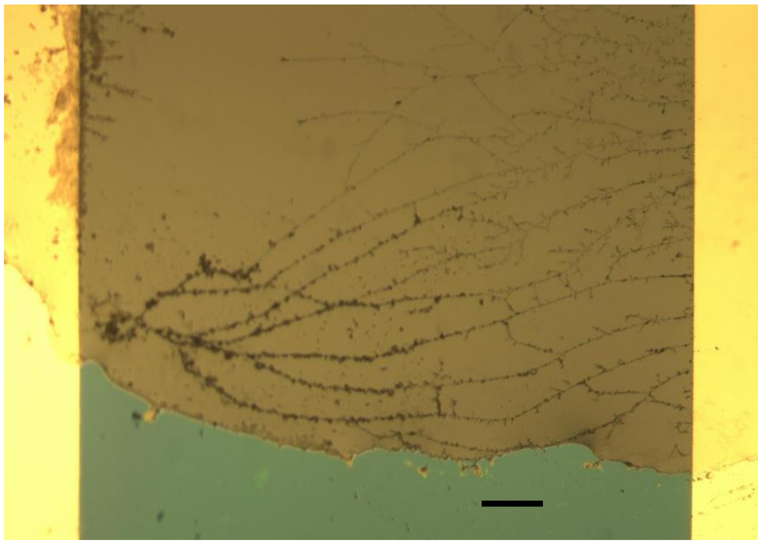

Figure 6. Optical image of gold wires fabricated between electrodes with 1 mm gap distance under $10V_{pp}$ AC at 200 kHz, with a 3 V DC offset. The 0.5 mM gold acetate solution was dropped on the gap. The scale bar denotes 100 μm.

4. Conclusion

In conclusion, the formation of gold nanowires using an electrolysis process can be affected by factors such as the magnitude of AC, DC offset, gaps between the electrodes and assembly time, etc. We are currently investigating their applications in the detection of chemical and biological species in solutions.

5. Conflicts of Interest

The author(s) report(s) no conflict(s) of interest(s). The author along are responsible for content and writing of the paper.

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7. References

1. Tian M, Wang J, J. Kurtz, Mallouk TE, Chan MHW. Electrochemical Growth of Single-Crystal Metal Nanowires via a Two-Dimensional Nucleation and Growth Mechanism. Nano Letters 2003; 3(7): 919-923.
2. Hulteen JC, Martin CR. A general template-based method for the preparation of nanomaterials. Journal of Materials Chemistry 1997; 7: 1075-1087.

3. Pena DJ, Mbindyo JKN, Carado AJ, Mallouk TE, Keating CD, Razavi B, Mayer TS. Template Growth of Photoconductive Metal-CdSe-Metal Nanowires. The Journal of Physical Chemistry B 2002; 106(30): 7458-7462.
4. Baitimirova M, Pastare A, Katkevics J, Viksna A, Prikulis J, Erts D. Gold nanowire synthesis by semi-immersed nonporous anodic aluminum oxide templates in potassium dicyanoaurate-hexacyanoferrate electrolyte. Micro & Nano Letters 2014; 9(11): 761-765.
5. Johnson LP, Matisons JG. Synthesis of High Aspect-Ratio Gold Nanowires with Highly Porous Morphology. ISRN Nanomaterials 2012; 2012: 502960.
6. Richter J, Seidel R, Kirsch R, Mertig M, Pompe W, Plaschke J, Schackert HK. Nanoscale Palladium Metallization of DNA. Advanced Materials 2000; 12(7): 507-510.
7. Wissner-Gross AD. Dielectrophoretic reconfiguration of nanowire interconnects. Nanotechnology 2006; 17(19): 4986-4990.
8. Kretschmer R, Fritzsche W. Pearl Chain Formation of Nanoparticles in Microelectrode Gaps by Dielectrophoresis. Langmuir 2004; 20(26): 11797-11801.
9. Hamers RJ, Beck JD, Eriksson MA, Li B, Marcus MS, Shang L, Simmons J, Streifer JA. Electrically directed assembly and detection of nanowire bridges in aqueous media. Nanotechnology 2006; 17(11): S280-S286.
10. Hermanson KD, Lumsdon SO, Williams JP, Kaler EW, Velec OD. Suspensions Functional Microwires from Nanoparticle Dielectrophoretic Assembly of Electrically. Science 2001; 294(5544): 1082.
11. Huang Y, Duan X, Wei Q, Lieber CM. Directed assembly of one-dimensional nanostructures into functional networks. Science 2001; 291(5504): 630-3.
12. Cheng C, Gonela RK, Gu Q, Haynie DT. Self-Assembly of Metallic Nanowires from Aqueous Solution. Nano Letters 2005; 5(1): 175-178.
13. Mishima TD, Talukdar I, Ozturk B. Directed growth of single-crystal indium wires. Applied Physics Letters 2006; 88: 221907.
14. Ozturk B, Talukdar I, Flanders BN. Directed growth of diameter-tunable nanowires. Nanotechnology 2007; 18(36): 365302.
15. Cheng C, Haynie DT. Growth of single conductive nanowires at prescribed loci. Applied Physics Letters 2005; 87: 263112.