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Abstract

Parameters Affecting Single ZnO Nanowire Assembly by Dielectrophoresis †

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Abstract: This study aims to examine the dielectrophoretic assembly of single ZnO nanowires, focusing on the effect of electrode geometry, AC frequency and solvent medium on the alignment performance. Experimental results indicate that the electrode geometry significantly affects the capturing performance due to the electric field distribution. Utilizing ethanol as the solvent medium resulted in repeatable nanowire alignment at the optimal AC voltage frequency.

Keywords: dielectrophoretic (DEP) assembly; hydrothermal ZnO growth; single ZnO nanowires

1. Introduction

Single ZnO nanowire (NWs) devices have received increased attention in the field of UV [1] and gas sensors [2], as well as in the fabrication of field-effect transistors [3] and resistive memory devices [4]; however, it is still challenging to manipulate and align single nanowires due to their small dimensions. Dielectrophoresis (DEP) has been utilized successfully in assembling single ZnO nanowires into functional devices [4]. This study focuses on the effect of electrode geometry, AC frequency and solvent medium on the alignment performance of single ZnO nanowires on metal electrodes for the fabrication of functional devices.

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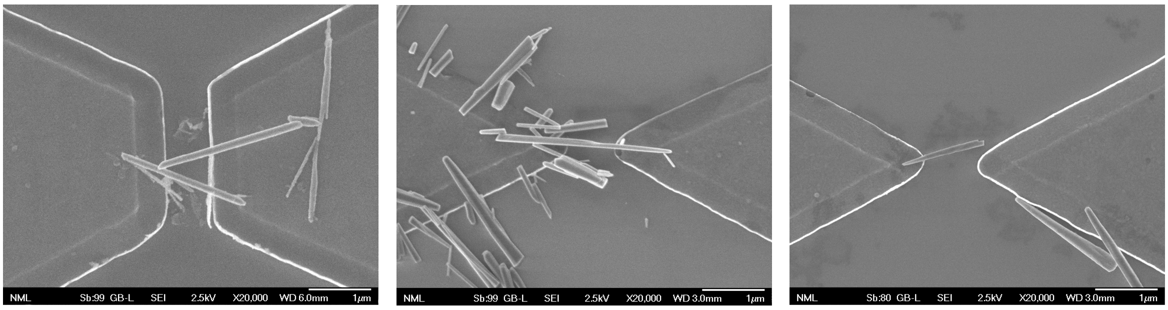
2. Materials and Methods

Long (5.4 ± 0.3 µm) ZnO NWs have been hydrothermally grown on sol–gel seeded Si substrates. Triangular and flat-shaped microelectrodes (1 µm gap) were used in the DEP assembly of the ZnO NWs, fabricated by e-beam lithography (EBL) and a conventional lift-off process, resulting in 100 nm thick Al electrodes on top of p+ Si/SiO2 substrates. The resulting ZnO NWs were dispersed in 10 mL of deionized water (DIW) and ethanol via ultrasonication for 15 min, creating a uniform NW suspension. A 2 µL droplet was placed on the microelectrodes containing ZnO NWs and an AC voltage was applied between the electrodes with a peak-to-peak value of 5 Vpp at a frequency range of 50 kHz to 1 MHz.

3. Discussion

Figure 1a shows the SEM image of a single nanowire bridging the gap between the flat electrodes using the DIW suspension. The alignment is imperfect due to the geometry of the electrode pairs, since the DEP force increases with the gradient of the squared field intensity [1], becoming stronger at the sharp electrode corners where the electric field is uniform. However, alignment results were sporadic for both flat and triangular electrodes, which was attributed to the use of DIW as the solvent medium. By using ethanol as the solvent medium, repeatable capture events were achieved, as shown in Figure 1b, even when the relative permittivity of ethanol was larger than that of ZnO, since positive DEP is produced when the dielectric constant of the nanowire is higher than that of the medium as defined by the Clausius–Mossotti factor [5]. The optimum assembly frequency was found to be at the range of 500 to 600 kHz. Successful assembly occurs when a nanowire is connected to one side of the electrode and is of sufficient length in order to bridge the gap. Figure 1c shows the case where a single nanowire is assembled at the middle of the electrode; however, it cannot bridge the gap due to its length.



(**a**) (**b**) (**c**)

Figure 1. SEM images of single ZnO NWs assembled via DEP: (**a**) using DIW as a solvent and (**b**) using ethanol as a solvent; (**c**) a single ZnO NW arrested on one electrode, unable to bridge the gap due to its length. The scale bars are 1 μm.

4. Conclusions

In summary, hydrothermally grown ZnO nanowires were successfully assembled between Al electrodes with 1 μm gap utilizing a DEP AC assembly process. The frequency range for successful capture of single ZnO nanowires was identified in the range of 500 to 600 kHz at an AC voltage of 5 Vpp. The geometry of the electrodes had a profound effect on the alignment of the assemble nanowires due to the difference in the electric field distribution along the gap. Finally, using an ethanol nanowire suspension resulted in repeatable capture of ZnO nanowires, either on a single electrode or bridging the gap depending on NW length.

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References

1. Ding, H.; Shao, J.; Ding, Y.; Liu, W.; Tian, H.; Li, X. One-Dimensional Au-ZnO Heteronanostructures for Ultraviolet Light Detectors by a Two-Step Dielectrophoretic Assembly Method. *ACS Appl. Mater. Interfaces* **2015**, *7*, 12713–12718. [CrossRef] [PubMed]
2. Mohseni Kiasari, N.; Servati, P. Dielectrophoresis-Assembled ZnO Nanowire Oxygen Sensors. *IEEE Electron. Device Lett.* **2011**, *32*, 982–984. [CrossRef]
3. Chang, Y.K.; Chau-Nan Hong, F. The Fabrication of ZnO Nanowire Field-Effect Transistors Combining Dielectrophoresis and Hot-Pressing. *Nanotechnology* **2009**, *20*, 235202. [CrossRef] [PubMed]

4. Wu, X.; Cui, N.; Zhang, Q.; Xiong, X.; Zhu, T.; Xu, Q. ZnO Single-Nanowire Schottky Barrier Resistive Switching Memory Assembly with Dielectrophoresis. *J. Electron. Mater.* **2022**, *51*, 7190–7197. [CrossRef]
5. Maijenburg, A.W.; Maas, M.G.; Rodijk, E.J.B.; Ahmed, W.; Kooij, E.S.; Carlen, E.T.; Blank, D.H.A.; ten Elshof, J.E. Dielectrophoretic Alignment of Metal and Metal Oxide Nanowires and Nanotubes: A Universal Set of Parameters for Bridging Prepatterned Microelectrodes. *J. Colloid Interface Sci.* **2011**, *355*, 486–493. [CrossRef] [PubMed]