ALIGNING NANOWIRES BY STANDING SURFACE ACOUSTIC WAVES

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ABSTRACT

We present a standing surface acoustic wave (SSAW) based approach to achieve one-dimensional (1D) and two-dimensional (2D) alignment of nanowires (NWs). Our SSAW-based nanowire-aligning technique can be used to construct large-scale (e.g., centimeter scale) network of nanowires within 5 min. In this approach, we use interdigital transducers deposited on a piezoelectric substrate to generate different standing SAW fields, which induce AC electric fields on the substrate and in turn align suspended metallic nanowires in the fluidic chamber. This effect is coined as standing SAW-induced dielectrophoresis (DEP). By controlling the standing SAW field, we show that metallic nanowires can be bundled and aligned in one-dimensional (1D) standing SAW fields, or assembled into networks in two-dimensional (2D) standing SAW fields. We can achieve different patterns of nanowires by changing the distribution of pressure and electric field with different arrangements of interdigital transducers (IDTs). Moreover, three-dimensional (3D) spinning of nanowires are observed near the acoustic pressure antinodes of a 2D standing SAW field. The technique presented in this paper possesses advantages of tunability, high throughput, and low cost, which has the potential to be adopted in electrical, optical, and biological applications.

KEYWORDS

Nanowire, Alignment, Standing Surface Acoustic Wave, Piezoelectric Field.

INTRODUCTION

One-dimensional (1D) nanostructures such as nanowires or nanotubes are critical components in the construction of functional micro/nano-devices for electrical applications and biomedical assays. Over the past decade, researchers have made great progress on synthesizing 1D nanostructures while manipulation of nanowires/nanotubes remains a big challenge. A variety of techniques have been recently developed to manipulate (align, pattern, and spinning, etc.) nanowires [1-3]. However, most of these methods could only achieve one specific function in nanowires/nanotubes manipulation without much flexibility in the operation process. To overcome these weaknesses, our approach was developed to realize controllable manipulation with multiple functions.

Acoustic-based techniques, have been recently developed to pattern microparticles and cells in a quick and controllable fashion due to the standing SAW-induced pressure fluctuations in microfluidics [4, 5]. Different from the microparticle patterning, acoustic tweezers manipulate nanowires based on standing SAW-induced piezoelectric fields instead of acoustic radiation forces. As a result, nanowires show distinct behaviors compared to microparticles in standing SAW fields. In our work, it is the first time to use standing surface acoustic waves for patterning of nanowires into two-dimensional arrays. Similar to 'optoelectronic tweezers' [6], standing SAWs induces virtual electrodes at different locations on a Lithium niobate (LiNbO3) substrate, resulting in variable electric field distributions which pattern nanowires via dielectrophoretic (DEP) forces. Further optimizing this technique, acoustic tweezers could achieve surface patterning in a scale of square centimeters with high flexibility in several parameters, such as the spacing of nanowires.

EXPERIMENT

In our approach, two pairs of IDTs were deposited orthogonally on a LiNbO3 substrate and used to generate 1D (Figure 1a) or 2D (Figure 1b) SSAW fields. Before applying SSAW, silver nanowire suspension was injected into a capillary gap between the LiNbO3 substrate and a glass slide. The nanowires were uniformly distributed in the capillary gap (Figure 2a). In the 1D SSAW field (Figure 1a), nanowires were assembled into bundles and aligned along the propagation direction of surface acoustic waves (SAW) (Figure 2b). These nanowire bundles were then arranged into rows perpendicular to the SAW propagation direction. The distance between the centers of two neighboring rows was half wavelength. The dynamic aligning/patterning process is shown in Figure 3. It took around 15 seconds to complete the 1D aligning process. When the SSAW field was switched into a 2D pattern, a 2D nanowire network was assembled (Figure 2c), in which nanowires were aligned and patterned two-dimensionally. The SEM image of nanowire bundles (Figure 4) shows that the nanowires were well assembled and deposited onto the substrate even after the solution was dried up.

We carried out negative control experiments to study the role of SSAW and electric field on the nanowire-aligning process. With a layer of coupling liquid below the nanowire suspension (Figure 5a), electric field was excluded; only SSAW field was transferred into the suspension. As shown in Figure 5b and 5c, the nanowire bundles moved to the pressure node without alignment, acting like microspheres. These results indicate that SAW-generated electrical field, rather than SSAW field, plays an important role in nanowire alignment. These experimental results agree well with our simulation on electric field on the nanowire-aligning process. Our technique provides a promising tool to pattern and align nano-objects. With further optimization, it can become valuable for many electrical, optical, and biological applications.

CONCLUSION

In summary, our work uses standing surface acoustic waves for tunable alignment and patterning of nanowires. We demonstrate that nanowires could be patterned into 1D or 2D arrays by standing SAW-induced piezoelectric fields in less than 5 min. A 3D sparking pattern was observed in 2D electric fields. We are able to switch the aligned direction, and transfer the 1D and 2D patterns into each other by controlling the electric field distribution. As a result, nanowire patterning using standing SAW have an excellent ability to pattern nanowires in the terms of versatility and tunability.

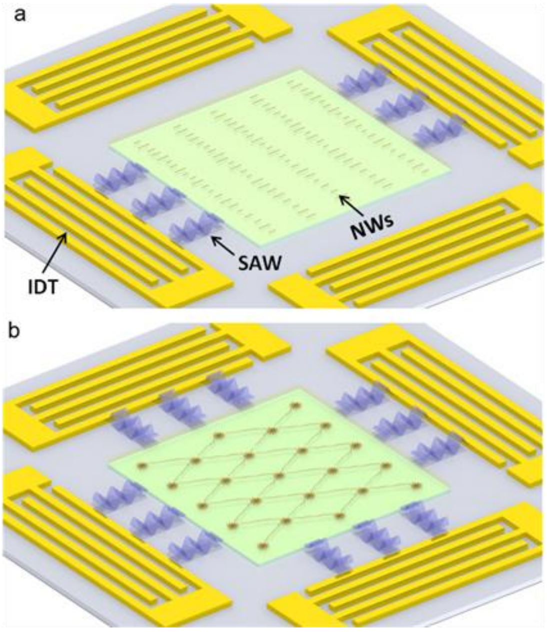

Figure 1. Schematic of the device-operation mechanism for a) one-dimensional, and b) two-dimensional nanowire alignment.

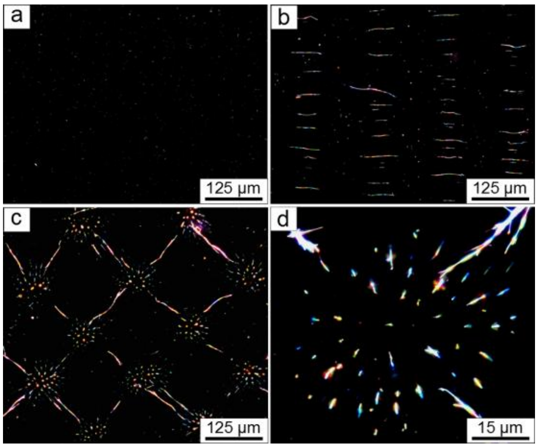

Figure 2. Image of Ag nanowire patterns: a) before aligning, b) one-dimensional aligning, c) two-dimensional aligning, and d) zoom-in of the pressure node in c).

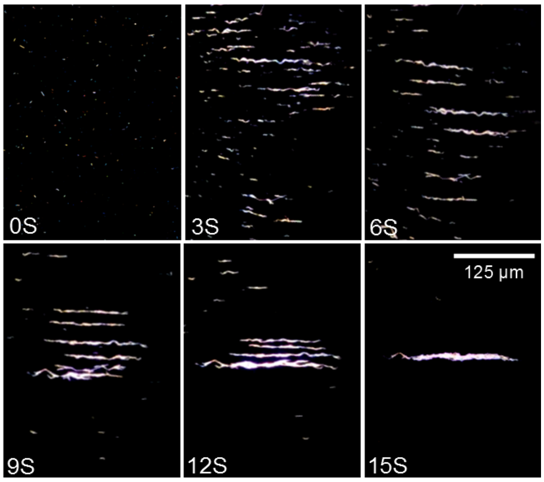

Figure 3. Dynamic nanowire assembly during the 1D nanowire-aligning process.

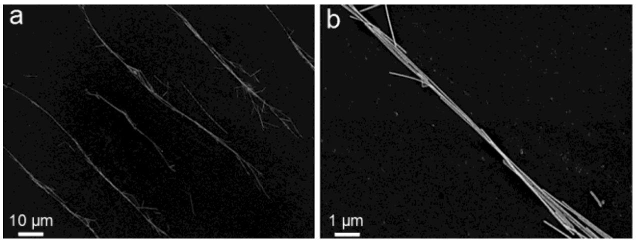

Figure 4. SEM image of assembled nanowires after the solution is dried up.

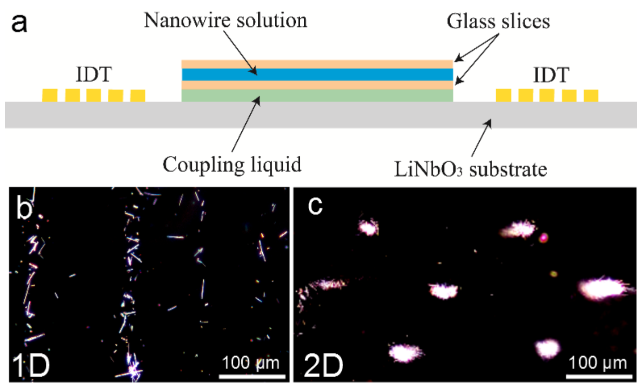

Figure 5. Negative control experiments: a) experimental setup; b) 1-dimensiaonl patterning without aligning; c) 2-dimensiaonl patterning without aligning.

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