Deterministic Assembly of Alternative Materials onto Silicon Substrates

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Abstract:

Deterministic assembly of III-V compound semiconductor devices offers the promise of enabling innovative functions that go beyond the conventional use of digital electronics. Recent studies have achieved controlled placement of metal and semiconductor nanowires via electric-field-assisted assembly techniques. However, many III-V optoelectronic and electronic devices that are interesting are considerably larger in size. In this project, we studied the electric-field assisted assembly of 100 nm thick and 10 μm long chromium (Cr) microtiles having widths of 1.2 μm, 2.4 μm, and 3.0 μm. The non-uniform electric field used to manipulate the microtiles was induced in the isopropanol (IPA) solution that suspended the microtiles by applying a 100 kHz, 20 Vp-p bias voltage to pairs of interdigitated metal electrodes patterned on a silicon nitride (Si_3N_4) coated silicon (Si) substrate. The electrodes pairs are separated by 3 μm wide gap, and were coated with a 1 μm thick photoresist layer. The results of the study showed that uniformly spaced arrays of all of the microtiles could be assembled using this technique. The space between adjacent tiles in the array depended on the width of the tile and the gap. These promising results provide a proof-of-concept for the assembly of III-V epitaxial device layers on Si substrates.

Introduction:

Silicon complementary metal oxide semiconductor integrated circuit (CMOS IC) technology is reaching the physical limits of transistor scaling. Consequently, there is an increasing interest in adding value to the circuits through functional diversification [1]. Integrating diverse devices onto Si IC's has the potential to enable new functions ranging from light detection and emission to highly sensitive chemical and biological detection. However, this requires the monolithic integration of many different kinds of materials, which are generally not compatible with conventional top-down fabrication methods. Electric-field assisted assembly has been used to deterministically position arrays of single nanowires on a Si substrate with high accuracy between each nanowire and a lithographically defined feature on a Si substrate [2].

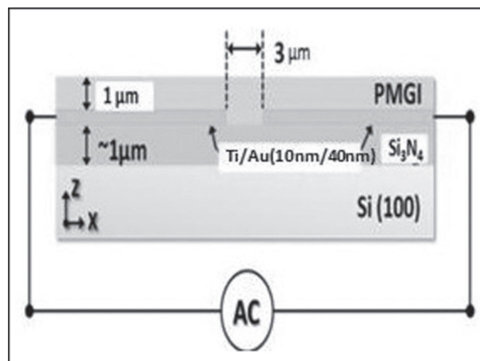

Figure 1: Cross section of the electrode.

The goal of this project was to assemble and study the deterministic assembly of much larger micron-size tiles using the same technique. In this study, chromium tiles were used as a model system to understand how changing the dimensions of the starting materials impact the deterministic assembly process. In the future, alternative materials such as III-V compound semiconductors will be assembled using this bottom-up approach.

Fabrication and Experimental Procedure:

The interdigitated electrode structure used for the assembly experiments, which is shown in Figure 1, was fabricated using standard i-line projection lithography. The electrode structures were fabricated on 3-inch diameter thermally oxidized Si substrates by exposing the patterns printed on a quartz reticle in a 3012 photoresist layer and developing the exposed photoresist in SF-11. Each substrate contained 92 separate reticle fields that were separated from one another prior to the deterministic assembly experiments. Following lithography, thermal evaporation was used to deposit 10 nm of titanium (Ti) and 40 nm of gold (Au) on the patterned Si substrate, and the metal on top of the unexposed photoresist was lifted off

using Microposit 1165 remover. A polydimethyglutarimide (PMGI) dielectric layer was coated onto the wafer and baked to form the planarized insulating spacer that separated the metal electrodes from the fluid used to suspend the microtiles during assembly. In parallel, the i-line stepper was also used to fabricate dense arrays of Cr microtiles having a length of 10 μm and varying widths of 1.2 μm, 2.4 μm and 3.0 μm using a similar liftoff process.

The microtiles were flowed across the assembly electrode structure in a fluidic channel that was formed by between a glass cover slip and the Si substrate. A manual probe station was used to electrically contact the assembly structure. A dielectrophoretic (DEP) force was induced on the microtiles by applying a sinusoidal bias voltage using a function generator with an amplitude of 20 Vp-p and a frequency of 100 KHz. Immediately prior to assembly, the IPA solution containing the Cr microtiles was sonicated for 20 seconds to ensure that aggregated tiles were separated and uniformly suspended. A 3 μl of Cr microtile solution was injected into the fluidic channel using a micropipette for assembly.

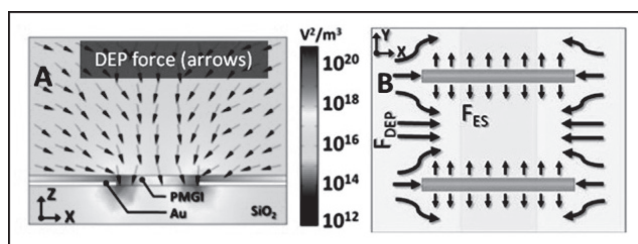

Figure 2: A) long-range dielectrophoretic force; B) Shorter-range electrostatic force.

Results and Conclusions:

The electric-field profile that defines the deterministic assembly process was simulated using COMSOL Multiphysics finite element modeling software. During the initial phase of the assembly process, long-range dielectrophoretic forces attracted and aligned the Cr microtiles across the interdigitated electrode gaps as shown in Figure 2a. Next, the shorter-range electrostatic interaction between adjacent Cr microtiles caused the tiles to space relatively uniformly in an array as shown in Figure 2b.

As shown in Figures 3a and 3b, the Cr microtiles were assembled according to the result predicted by our simulations. After analyzing the three different widths of Cr microtiles, we concluded that there is a dependency between the width of the Cr microtiles and the separation between the adjacent Cr microtiles. The numerical values of the spacing are shown in Figure 4.

This experiment demonstrated that the deterministic assembly technique can be applied to microtiles, and is viable for future experiments on a vast array of materials. Microtiles are currently being fabricated with indium gallium arsenide (InGaAs) to be integrated onto Si circuits.

Acknowledgements:

I would like to thank my mentor Scott M. Levin, my advisor Dr. Theresa M. Mayer, Kathy Gehoski, the National Nanotechnology Infrastructure Network Research Experience for Undergraduates, and the National Science Foundation.

References:

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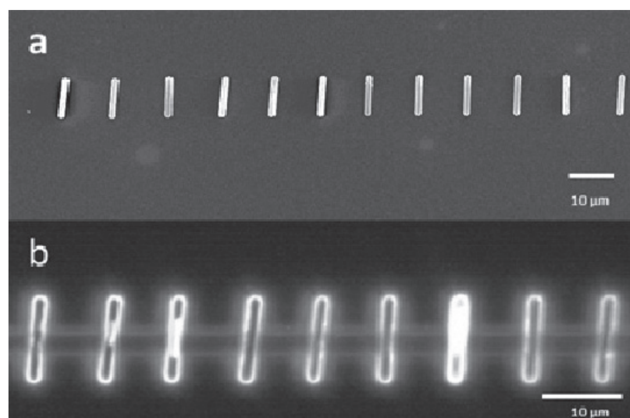

Figure 3: a) 1.2 µm Cr-microtile from FESEM; b) 3 µm Cr-microtile from optical microscope; dark field.

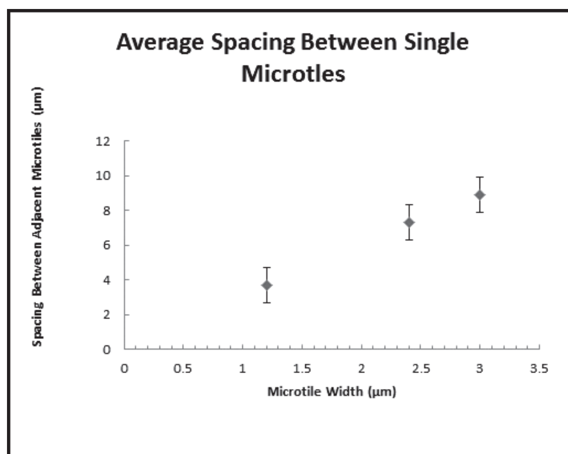

Figure 4: Microtiles of three different widths compared.