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LARGE-SCALE ASSEMBLY OF CARBON NANOTUBES

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ABSTRACT

The scale decomposition of a multi-scale system into small-scale order domains will reduce the complexity of the system and will subsequently ensure a success in nanomanufacturing. A novel method of assembling individual carbon nanotube has been developed based on the concept of scale decomposition. Current technologies for organized growth of carbon nanotubes are limited to very small-scale order. The nanopelleting concept is to overcome this limitation by embedding carbon nanotubes into micro-scale pellets that enable large-scale assembly as required. Manufacturing processes have been developed to produce nanopellets, which are then transplanted to locations where the functionalization of carbon nanotubes are required.

Keywords: Carbon nanotubes, Directed assembly, Multi-scale systems integration, Nanopelleting

DESIGN

Design and manufacture of nanostructure require much more precision than that of macro and microstructures. Many research groups have tried to build and control nanostructures bottom-up in this regard. The quantum dots, nanoparticles, nanotubes and nanowires are made with sub-nanometer accuracy, but have limited repeatability only within a short-range order. In order to benefit from the nanotechnology, nanostructures need to be integrated to the micro/macro-scale platforms, where the top-down and bottom-up processes meet.

Carbon nanotubes have been reported to have many unique and useful properties. Their integration into real applications requires robust large-scale assembly techniques. A key challenge to manufacture products with CNTs is handling of nano-scale objects during assembly. In particular, the construction of regular arrays of uniformly aligned CNTs requires control over the CNT orientation and location. Current techniques for large-scale CNT assembly utilize guided liquid dispersions, gas flow and electric field that do not provide deterministic control over the CNTs. [1-3] Other methods for CNT assembly control orientations during the growth step, particularly using plasma-enhanced CVD systems with pre-patterned catalysts. [4,5] Such techniques are effective in creating aligned CNTs with accurate location control, but are limited in their scale and order to very small areas. We developed a technique, termed *nanopelleting*, for the integration of CNTs into micro-scale pellets that can be transplanted and deterministically assembled.

The *nanopelleting* concept provides specific control over the length, alignment, and position of assembled CNTs. A nanopellet consists of a CNT embedded within a micro-scale pellet. The pellet serves as a carrier for the CNTs when they are integrated into multi-scale systems. Further, by decoupling the growth of CNTs from their use, pellets can be harvested and reassembled in bulk, enabling the fabrication of devices with long-range order and large scale.

PROCESSES and RESULTS

The fabrication process developed for nanopelleting relies on a combination of standard microfabrication steps as shown in Fig. 1. The steps to create a nanopellet include the creation of a trench within which CNTs are grown via PE-CVD process. The trenches are then filled with a spin coated epoxy polymer (M-Bond 610), encapsulating the CNTs. The surface is then planarized via CMP process to create pellets cast to the geometry of the trenches and CNTs with uniform alignment and length. The pellets and the embedded CNTs can then be released using a XeF_2 etch to selectively undercut only the silicon. Similarly, the pellet body material can be selectively removed without damaging the CNTs.

The results of this fabrication sequence demonstrate the capability of the process to encapsulate CNTs within the pellets that are then planarized to a uniform length, as shown in Fig. 2 (c). The pellet is removed from the original substrate by selectively under-etching the silicon. After the release, the pellets are then ready to be harvested and transplanted to an acceptor substrate. Variations in this process are also considered, including the use of additive techniques without trenches.

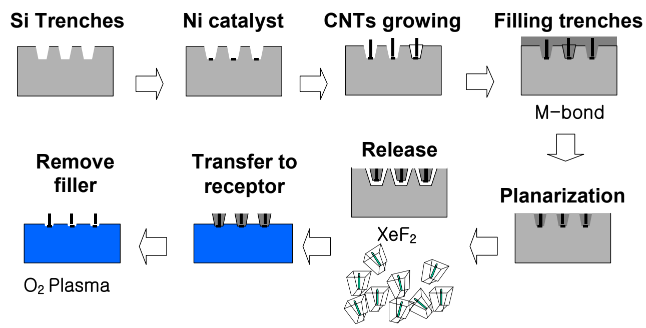
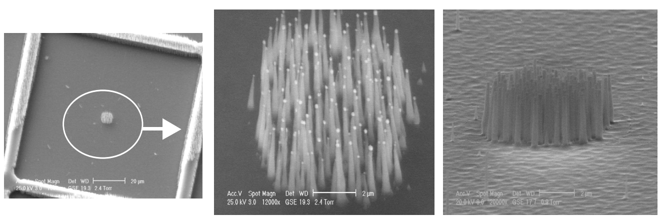


Figure 1: Representative process flow for creation of Nanopellets

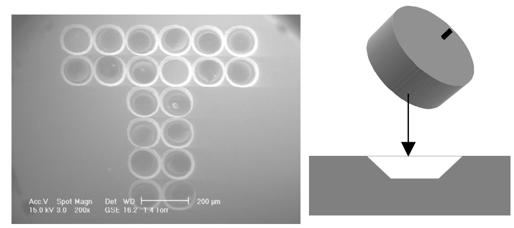


a) b) c)

Figure 2: a) A silicon trench with CNTs grown as a bundle at the center. Side view of CNTs before, (b), and after, (c), planarization showing uniform CNT length.

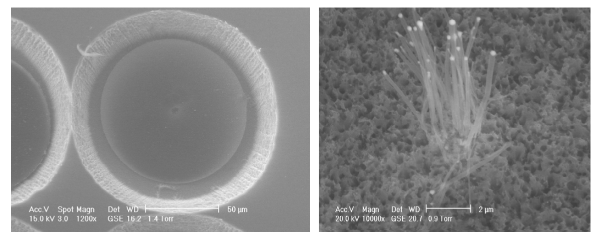
For transplanting of the pellets, we mechanically manipulated the micro-scale pellets onto an acceptor substrate with a pre-etched 'T' shape, as shown in Fig. 3 (a). Figure 3 (b) shows schematic view of transplanting a nanopellet onto a template. A magnified view of the pellet and embedded CNTs is shown in Fig. 4 (a) and (b) before and after the removal of dielectric material. Pellets are therefore effective in acting as a carrier that allows deterministic assembly of CNTs. Coupled with many self-assembly methods for micro-scale structures [6], large-scale assembly of CNTs would become possible by the *nanopelleting* process.

With the concept of nanopelleting, we have shown the possibility of guided assembly of individual nanotube into a long-range ordered 2-D array. The results support the nanopelleting concept as a means to produce large-scale arrays of CNTs with long-range order and deterministic positioning and alignment. Such a technique would enable applications that require large-scale arrays of CNTs with long-range order. This includes field emission systems for displays, massively parallel nanoprobing systems, or others. Moreover, given the broader applicability of the nanopelleting concept to nanostructures, the technique could also be used for handling and fabrication of other nanostructures. Further work on refining this technique for integration into actual applications is necessary, including high aspect ratio nanopellets.



a) b)

Figure 3: Transplanted pellet arranged into receptor trenches forming 'T' shape



a) b)

Figure 4: Pellet with CNTs in center, before XeF_2 etching, (a) and after XeF_2 etching, (b).

ACKNOWLEDGMENTS

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