PROCESSING

Nanotechnology meets bubbleology

A low-cost processing technique that is widely used to make polymer films is also capable of producing large-area films of aligned nanowires and nanotubes

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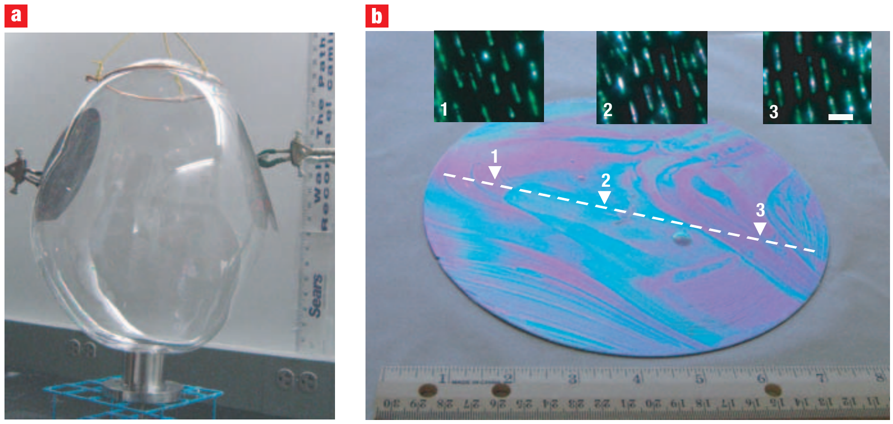

Figure 1 Blown-film extrusion is a promising technique for making nanocomposite films. **a**, A photograph showing the transfer of a bubble containing silicon nanowires suspended in a polymer to a pair of 150 mm silicon wafers. **b**, Image of a 200 mm silicon wafer onto which single-walled nanotubes have been transferred. The insets are dark-field images showing the alignment of the nanotubes at three different locations on the wafer. (See ref. 1 for full details.)

Many of us have happy childhood memories of blowing bubbles of soapy water through a pipe or a hollow ring. The art of 'bubbleology' has also been immortalized in the Broadway song 'I'm Forever Blowing Bubbles', although the chorus of the song is rather morose, with the songwriter comparing his dreams to bubbles that 'fade and die'. In a similar fashion, materials scientists have spent the last decade dreaming of an effective and scalable method to fabricate high-performance nanocomposite films, only for these dreams to be, in general, ultimately deflated.

However, such dreams may now be several steps closer to reality owing to a new process reported on the *Nature Nanotechnology* website today[1]. Guihua Yu and Charles Lieber of Harvard University and Anyuan Cao of the University of Hawaii at Manoa have developed a general and relatively facile bubble-based method to make large-area films of inorganic nanowires or carbon nanotubes in which both the alignment and the density of the nanostructures can be controlled. Moreover, the method — which involves expanding a bubble from a hybrid suspension of polymer and nanoparticles — should work for all nanoparticles. Yu and co-workers show that the films produced with the new approach are easily transferable to various substrates, and they go on to demonstrate that blown-bubble films are an elegant way to produce large-area arrays of nanostructures that may be suitable for applications as diverse as integrated electronics and sensor arrays.

Despite the many potential applications of semiconducting nanowires and nanotubes, our inability to controllably assemble these nanostructures into macroscale systems remains a major bottleneck in efforts to commercialize this technology[2,3]. There is a real need to develop practical technologies for transforming the as-produced raw nanowires and nanotubes into materials or integrated assemblies with properties that are both fundamentally interesting and useful for applications.

This is particularly true for nanotubes. For example, single-wall nanotubes synthesized by the popular HiPco (ref. 4) or laser vaporization[5] methods are produced as insoluble soot, which is very difficult to work with. A popular way to process this soot into thin films normally requires chemical or physical functionalization to render the nanotubes soluble, followed by mixing with a matrix polymer to form a composite and, finally, spin casting the composite onto a substrate. This is by no means an ideal process. The resulting films typically have a non-uniform distribution of nanotubes due to the agglomeration that occurs during solvent quenching. The evaporation of the solvent is also influenced by the air flow and, as a result, the process takes place at a very high speed and can lead to the nanotubes aggregating in small domains, which is not useful for applications. Moreover, this methodology is not suited for the production of large-area films. Although other techniques such as Langmuir–Blodgett assembly have been successful, it is unlikely that such methods will prove to be scalable or commercially viable.

The process developed by the Harvard–Hawaii team is based on a manufacturing method that is widely used to make everyday items such as garbage bags and food packaging. Blown-film extrusion involves pulling a polymer through a die, followed by bubble-like inflation. The polymer bubble subsequently collapses to form continuous flat films with regulated width and thickness. Using homogeneous suspensions of semiconducting nanowires or carbon nanotubes (functionalized with large organic groups) in a polymer epoxy, Yu, Cao and Lieber show that blown-film extrusion is an ultra-adaptable and relatively facile method for making large-area assemblies of nanoparticles that can be deposited on a range of substrates, both flat or curved. And by carefully controlling the processing conditions, it is possible to control both the alignment and density of the nanowires or nanotubes in the films.

The team demonstrates that the resulting films can be deposited onto 200-mm-diameter wafers and onto plastic sheets with areas greater than 225 × 300 mm. Moreover, using standard processing techniques, they fabricate an array of field-effect transistors based on silicon nanowires. Encouragingly, regular polymer films made with the bubble approach can exceed metre-scale areas and may also be deposited as three-dimensional structures using modified rigs. This existing know-how will surely help enormously as researchers develop and refine the technique for the production of nanocomposite films.

However, despite the exciting possibilities offered by this new process, several issues will have to be addressed in the short term before nanocomposite assemblies produced this way can be used in real-world applications, such as the manufacture of sensor arrays. First, in the present process, relatively low concentrations of nanotubes and nanowires are dispersed in the 'blowing' solution. Consequently, for large-area films, the distance between individual nanostructures is relatively large (greater than 2 μm). Ultimately, however, this may not be a major bottleneck as other groups have shown increased loading levels in other dispersion systems[6]. Second, the dynamics of the process is only qualitatively understood. For instance, it is intriguing that the separation between the nanoparticles is so uniform because suspensions such as these are prone to various kinds of instabilities that might disrupt such uniformity.

There is no doubt, however, that once these issues are addressed and the process is further optimized, the production of nanowire and nanotube films using blown-film extrusion will be an important advance for many application areas.

References

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