Wafer scale fabrication of AFM probes with carbon nanotube tips using a nanostencil

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Carbon nanotubes are used as tips for AFM probes in order to obtain high resolution[1] and to be able to image high aspect ratio structures[2]. Many different methods have been proposed to integrate a carbon nanotube on the tip of an AFM cantilever. Some methods involve manual placement and in some cases gluing of the carbon nanotubes to the AFM tip[2], whereas other methods are based on the direct growth of a carbon nanotube on an AFM cantilever[3,4].
Direct growth of carbon nanotubes requires fabrication or placement of a catalyst particle on the AFM cantilever, at the location where the nanotube tip should have its base. The catalyst particle can either be incorporated as an integral part of the AFM cantilever fabrication before the AFM probe is released[4] or as a separate add-on step after the release[3]. Integration of the catalyst particle with the AFM probe fabrication involves protecting the catalyst particle from wet and dry etches that would otherwise damage it. This becomes increasingly difficult with smaller catalyst particles or in the case where the catalyst particle has to be positioned at the apex of a silicon tip. Fabricating the catalyst particles after the release of the AFM cantilevers may on the other hand be difficult since deposition of resist by both spinning and spraying with a good edge coverage is at best very difficult.
The stencil technology provides a non-invasive, cheap and versatile way of transferring these catalytic nanostructures to a substrate. A stencil mask consists of a thin membrane in which apertures have been etched (figure 1a). By placing the stencil mask on top of a substrate and subsequently depositing a material through the openings in the membrane the structures are transferred (figure 1b). In addition to this, the stencil mask can be cleaned and reused[5], which makes it a potentially cheap fabrication method. Stencil technology has proven useful for the transfer of structures from hundreds of micrometers[6] to tens of nanometers[7], and since the stencil mask only needs to touch the substrate on the periphery it is possible to transfer structures to 3D surfaces[8]. As an alternative to carbon nanotubes epitaxially grown nanowires can be formed from catalyst particles and here it is advantageous that no chemicals are needed which could damage the substrate.
In this work, we transferred catalyst particles for carbon nanotube growth at specific locations onto a wafer of released AFM probes (figure 2). The AFM probes are only attached by a single silicon beam so that after the catalyst deposition and carbon nanotube growth they can be picked out of the wafer by a pair of tweezers. It is shown that catalyst particles can indeed be transferred onto these free-hanging AFM probes on a wafer scale and that carbon nanotubes can be grown vertically on the tip using a PECVD process (figure 3). The alignment of the catalyst particle over the full wafer was done with an accuracy of ±1µm or better, which allows the nanotubes to be placed close to the edge of the cantilever. In figure 4 an AFM cantilever with a single carbon nanotube placed 2 µm from the edge is shown. The carbon nanotube was grown from the catalyst particle, which was deposited on the substrate through a 300 nm hole in the stencil. This project shows the way for a versatile and cheap method for wafer scale fabrication of AFM probes with carbon nanotube tips, while several other applications are possible; free-standing resonators, mechanical switches, electron field emitters.

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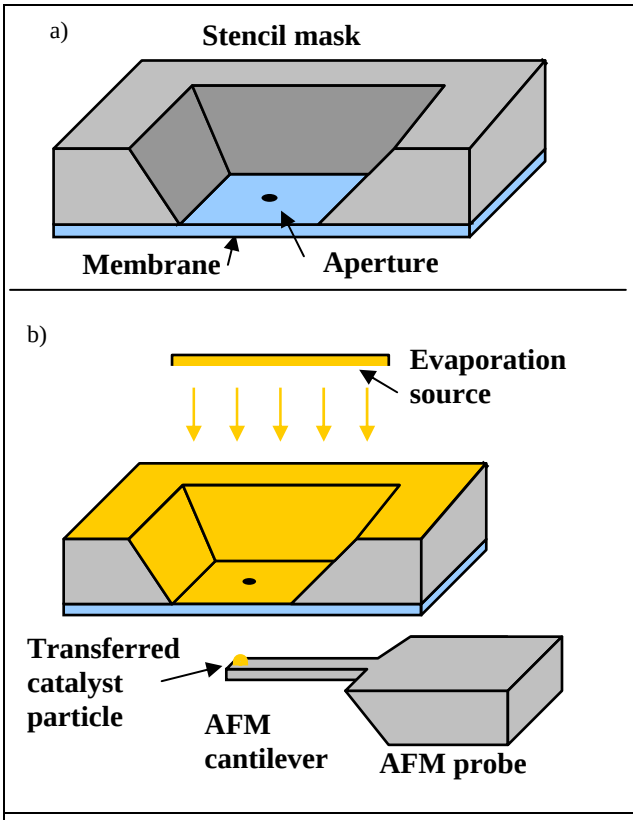

Figure 1. a) A stencil mask. b) The process of making a stencil transfer. Nickel was transferred to the AFM cantilever.

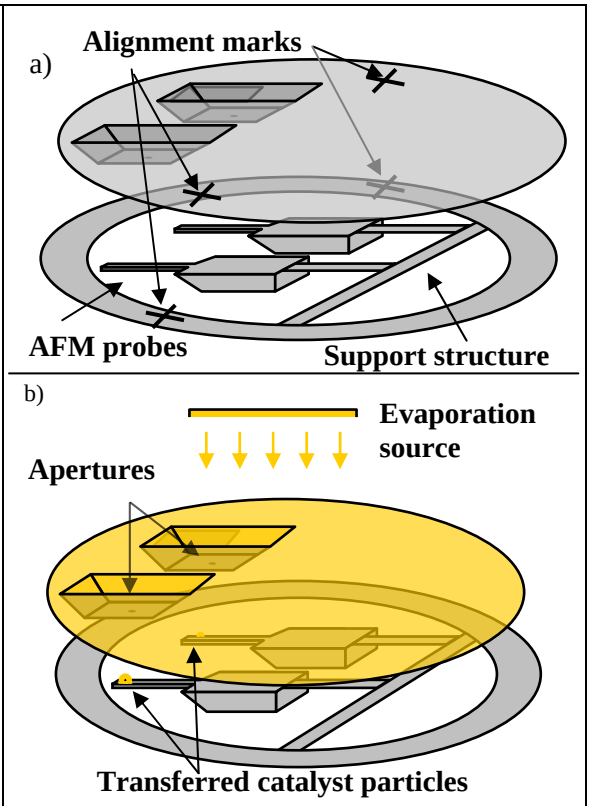

Figure 2. a) Stencil and wafer was aligned using alignment marks b) Nickel was evaporated through the apertures to the probes.

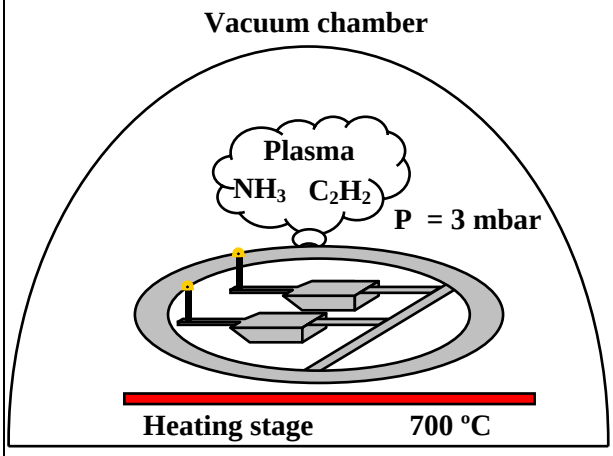

Figure 3. The carbon nanotubes were grown in a PECVD chamber which made them vertically aligned.

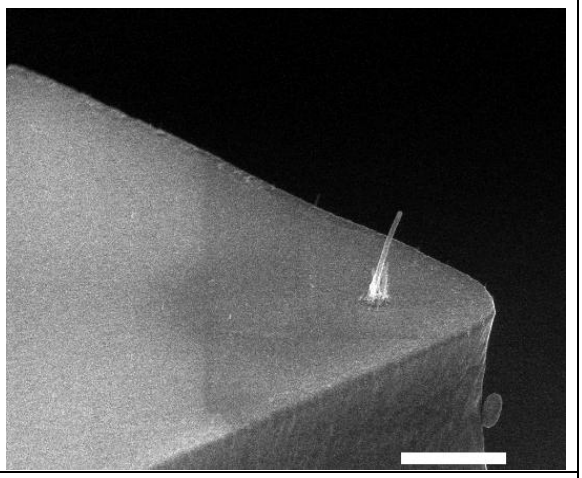

Figure 4. An electron micrograph of the end of an AFM cantilever with a carbon nanotube tip. Scale bar is 2 µm.