Towards waferlevel fabricated CNT sensors – Process improvements by length separation of single-walled carbon nanotubes

Simon Böttger[1], Sascha Hermann[1], Stefan E. Schulz[1,2]

[1]Technische Universität Chemnitz, Center for Microtechnologies, Reichenhainer Str. 70, 09126, Chemnitz, Germany
[2]Fraunhofer Institute for Electronic Nano Systems (ENAS), Technologie-Campus 3, 09126, Chemnitz, Germany
simon.boettger@zfm.tu-chemnitz.de

Abstract

Single-wall carbon nanotubes (SWCNTs) show unique and outstanding mechanical properties like high young's modulus and tensile strain. Furthermore depending on the chirality of the SWCNTs they show piezoresistive gauge factors up to 2900 [1], which is one order of magnitude higher than common silicon strain sensors. Therefore CNTs are promising candidates for mechanical, especially piezoresistive sensing. The aim of our project is a waferlevel fabrication of mechanical strain sensors based on the piezoresistive effect of horizontally aligned SWCNTs. Therefore it is mandatory to reproducible deposit homogeneous assemblies of CNTs which can be realized with the dielectrophoretic deposition (DEP) as already shown by our group on waferlevel [2]. Furthermore a sufficient CNT length distribution is required in order to prevent chain formation in the transistor channel and to afford reliable electrical and mechanical contacting. Therefore the pre-selection of the CNT raw material according to length is a prerequisite for a successful waferlevel integration of CNTs into field effect transistors (FETs) which is the basic element in a piezoresistive transducer. This pre-selection is realized by size-exclusion chromatography (SEC) as already presented in literature [3]. Moreover we integrated length separated SWCNTs in FETs and investigated their performance

The first step is the preparation of a homogeneous CNT dispersion by sonification and centrifugation of SWCNTs dispersed in a surfactant solution of sodium monohydrate deoxycholate (DOC) and deionized water. After that we perform the length separation with SEC by using a single column setup filled with a porous particle gel of a certain pore size. By applying a constant flow rate Φ to the column, an interaction between dispersed SWCNTs and the gel particles leads to a different retention time depending on the length of the tubes separating them by length. Finally fractions of length separated CNT dispersions are collected and furthermore characterized with UV-Vis-NIR and Raman spectroscopy. Afterwards the CNTs were deposited by DEP on Pd electrode structures for length measurements of individual SWCNTs by atomic force microscopy (AFM) and scanning electron microscopy (SEM).

From Raman and UV-Vis-NIR absorption spectra of length separated CNT fractions we extract some CNT-specific peak values. The aspect ratio (height/FWHM) of the Raman G'-peak and of the S_{11} transition peak from the absorbance spectra over the elution volume show a characteristic elution profile of the separation process itself (Fig. 1). Additionally the length separation was confirmed by AFM and SEM studies of CNTs assembled on pre-structured Pd electrodes (Fig. 2). As expected CNT length decreases with increasing elution volume. To quantify this results a statistical length analysis of over 200 CNTs from several fractions was performed and the length distribution for both original dispersions and length separated fractions were extracted (Fig. 3). The length distribution of the separated fractions was narrowed with respect to the original dispersions which give rise to homogeneous and well aligned CNT films. Moreover a systematic variation of different process parameters and their influence on the length distribution was done (e.g. flow rate and purity of raw material). Finally the CNTs were deposited into FET structures and the influence of separation on structural and electrical properties was investigated.

References

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Figures

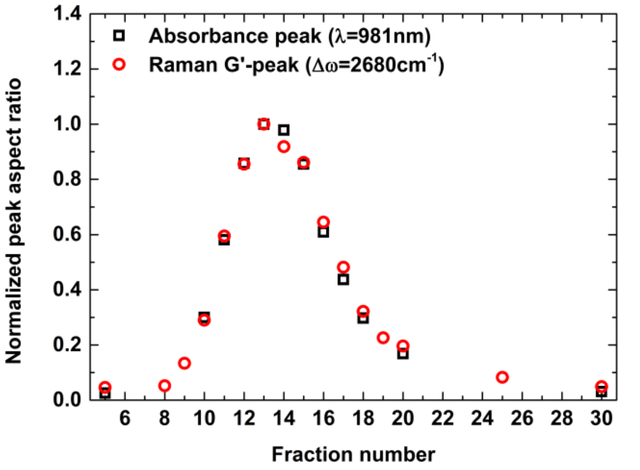

Figure 1: Characteristic elution profile of length separated carbon nanotube dispersions extracted from Absorbance and Raman spectra.

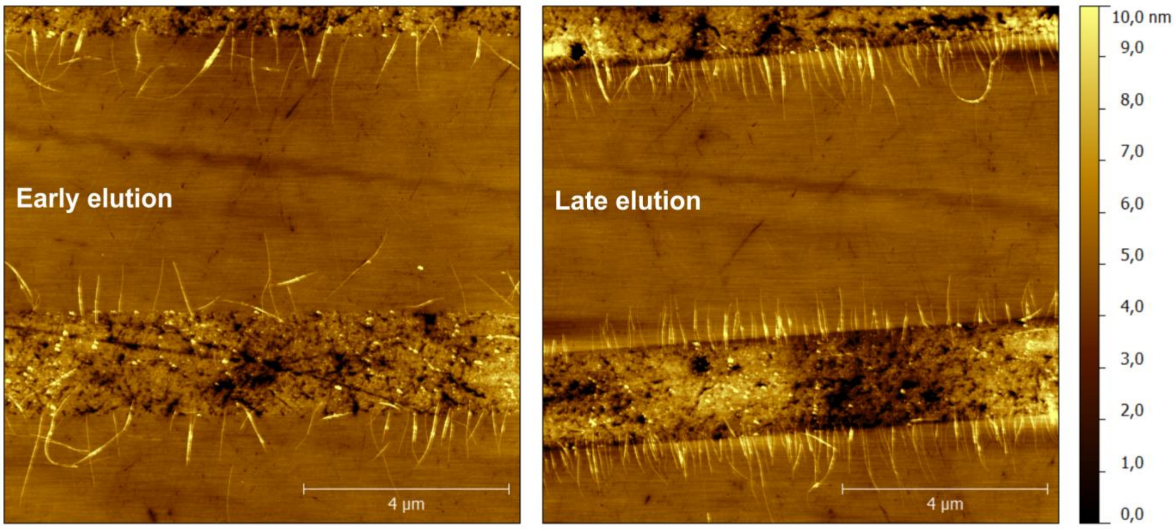

Figure 2: Assemblies of length separated carbon nanotubes deposited with dielectrophoretic deposition on Pd electrodes. Tube length decreases with increasing fraction number.

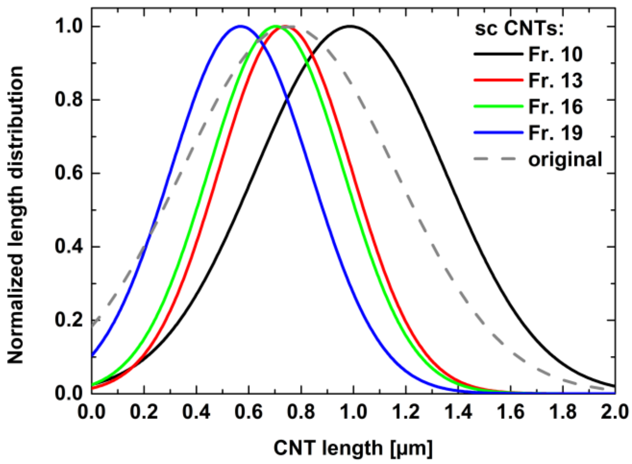

Figure 3: Length distribution of raw carbon nanotube material and length separated carbon nanotubes from different fractions.