Integration of Carbon Nanotubes in Interconnect Systems and Sensors

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1 Introduction

Carbon nanotubes (CNTs) attracted huge interest in the field of nanoelectronics and sensors due to their outstanding physical properties. In interconnect systems of ultra-large scale integrated (ULSI) circuits, where metals are increasingly confronted with electromigration, heat dissipation as well as fabrication issues due to continuous downscaling, CNTs are seen as a promising alternative interconnect material. Besides, CNTs facilitate a wide range of different sensors with new functionalities and high sensitivity. However, despite a huge progress in research on CNTs, complete integration of CNTs in different applications with scalable and reproducible technologies remains challenging.

2 CNT interconnects

In our group one field of activity is concerned with technological developments on CNT based vertical interconnects (vias) in ULSI circuits (Figure 1).

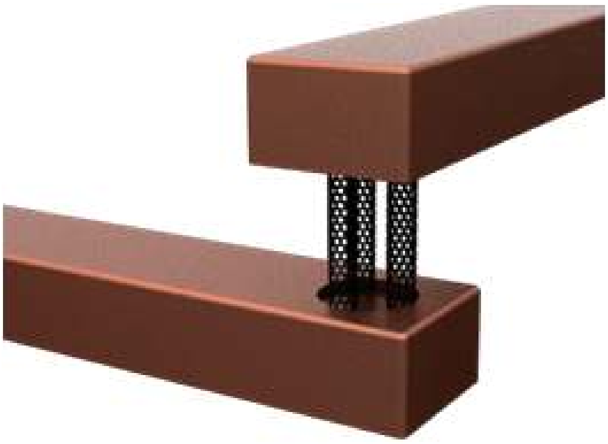

Fig. 1: Schematic of vertical CNTs in a CNT/metal hybrid interconnect system

Therefore systematic studies on CVD processes were conducted aiming growth of dense and vertically aligned multi-walled CNTs (MWCNTs). Those experiments were performed in a home-made vertical CVD reactor capable to process wafers up to 4 inch. Especially the role of the catalyst supporting layer was investigated [1]. Key results are CNT growth processes with adjustable growth mode and growth inhibition through adjustment of the support/catalyst system and the process (Figure 2 a, b). In the scope of those investigations a novel CNT film structure was obtained which was defined as interlayer CNT (ICNT) structure. Those films are characterized by a high homogeneity of CNT height and a continuous metallic catalyst layer system carried on the CNTs. The special structure enables an improved and simplified integration technology for CNTs in interconnect systems and a variety of other applications, which are currently under investigation. Additionally, CNT via structures were fabricated as shown in Figure 2 c. A homogeneous filling of via holes with vertically aligned MWCNTs was demonstrated on 4 inch wafers. Equally we were able to lower the growth temperatures down to 400° C, which demonstrates CMOS compatibility.

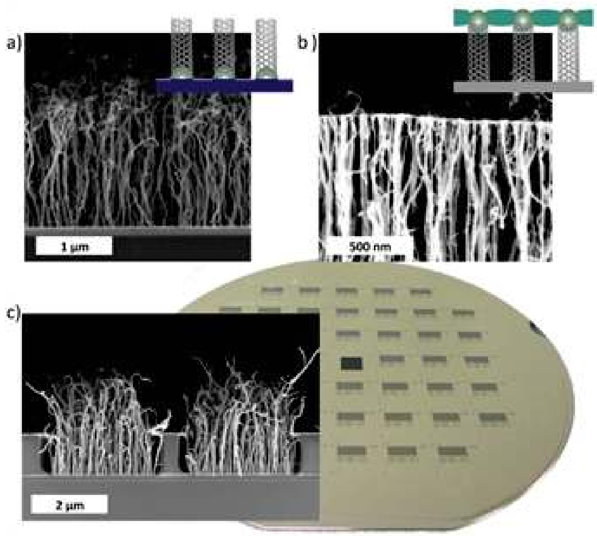

Fig. 2: Vertically aligned MWCNTs grown in root growth mode (a), novel interlayer CNT film structure (b), CNT via interconnect test structure (c), and 4" wafer after CNT process (background).

Ongoing developments focus on the fabrication of CNT/low-k interconnect structures with optimized interfaces between CNTs and the metallization to improve electrical and thermal properties. Those studies are supported by ab-initio modeling of the CNT/metal interface based on quantum mechanics. Furthermore, structural and electrical characterizations of CNT vias are underway.

3 CNT based sensors

Another emerging field is the application of CNTs in different sensors. In the focus there are electro-mechanical transducers with a high signal-to-noise ratio and high operation frequency. Envisaged applications are inertial, deformation, and high frequency vibration sensors. To detect very small relative movements especially the outstanding piezoresistive effect of single-walled CNTs (SWCNTs) is of interest. However, fundamental as well as technological challenges thwart realization of those sensors so far. Major issues are large scale assembly of specific SWCNTs, good metal/SWCNT interfaces, and complete integration solutions accommodating scalability and high reproducibility.

In our group systematic investigations and developments on the integration of SWCNTs and MWCNTs in sensor test structures are in progress. For the dielectrophoretic (DEP) assembly of CNTs from dispersions extensive preliminary studies on the preparation and characterization of different CNT dispersions have been conducted. Methods and routines have been compiled to prepare high quality CNT dispersions with a high reproducibility. Effects of preparation parameters like sonification power and time have been systematically studies as exemplarily presented in Figure 3. Furthermore, issues like strong length and quality variation of CNT raw material are addressed with centrifugal separation.

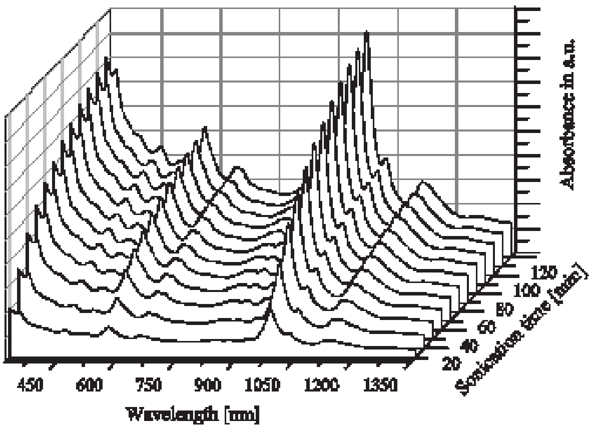

Fig. 3: UV-Vis spectra of SWCNT dispersions treated with different sonification times.

For the dielectrophoretic assembly of CNTs removable microfluidic channels are used to locate the dispersion flow only at electrode sites. There CNTs are deposited in an inhomogeneous electric field at high frequencies. Processes for the deposition of CNT films with aligned CNTs have been developed. Likewise good progress has been made towards aligned single-CNT assembly (Figure 4). Another important aspect is the optimization of the CNT/metal interface. Therefore different technologies are under development facilitating for instance the defined contacting of CNTs with Pd. Furthermore, equipment and process de-velopments for large scale integration of CNTs are in progress. Thereby homogeneous assembly of CNTs on wafers up to 6 inch has already been demonstrated.

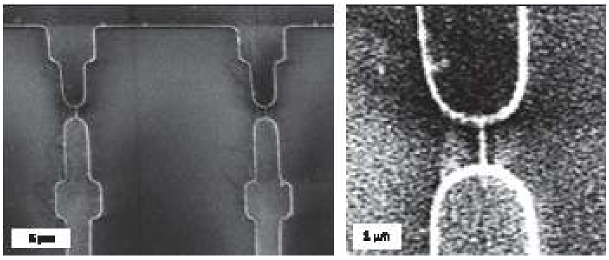

Fig. 4: Aligned SWCNTs between finger electrodes.

Ongoing developments include the fabrication of test structures in FET configuration adapted to the specific requirements of transducers based on the piezoresistive effect of SWCNTs. Special emphasize is paid to type selection of certain semiconducting SWCNTs, modification of SWCNT properties through functionalization, self-limited deposition, and interface engineering for resilient electrical/mechanical contacts. Besides, CVD processes for the growth of semiconducting SWCNTs are under development using a new processing system equipped with advanced in-situ analytics.

4 Acknowledgement

We acknowledge funding obtained by the DFG in the International Research Training Group GRK1215 "Materials and Concepts for Advanced Interconnects" and the Forschergruppe 1713 "Sensorische und Mikro- und Nanosysteme". Furthermore, we acknowledge financial support from the Volkswagenstiftung in the project "Integration of dielectrophoretic deposited Carbon Nanotubes and their reliability in mechanical sensor systems".

5 References

[1] Submitted PhD thesis: S. Hermann "Growth of carbon nanotubes on different support/catalyst systems for advanced interconnects in integrated circuits".