Nano Communication Networks 3 (2012) 175–182

Contents lists available at SciVerse ScienceDirect

Nano Communication Networks

journal homepage: www.elsevier.com/locate/nanocomnet

Review Article

Towards realisation of mixed carbon nanotube bundles as VLSI interconnects: A review

P. Uma Sathyakam, P.S. Mallick *

School of Electrical Engineering, VIT University, Vellore-632014, TN, India

ARTICLE INFO

Article history:
Received 20 January 2012
Accepted 11 September 2012
Available online 18 September 2012

Keywords:
Carbon nanotubes
Mixed CNT bundles
MWCNTs
SWCNTs
Transmission line modelling
VLSI interconnects

ABSTRACT

Carbon nanotube based interconnect technology is becoming popular for its various merits over the current copper technology. The ability to conduct high current at high temperatures through the 1D structure is making the CNT interconnect technology an attractive one. Single wall and multi wall CNT interconnects have received greater interest initially when the mixed CNT bundles (MCBs) did not get much attention as VLSI interconnects. But, it was only in 2007 when the conductance study of mixed CNT bundles was done and since then many works have been reported. At this stage, it is essential to review the reports of MCB based interconnect technology. We present in this paper, the first review on MCB VLSI interconnects.

Contents

1. Introduction

Carbon nanotubes have received remarkable interest in the IC manufacturing industry during the last decade. Due to their extraordinary physical and chemical properties, CNTs are regarded as ideal material for future on-chip VLSI and SoC interconnects in ultra deep sub micron (UDSM) technologies. The existing Cu interconnect technology has reached its peak scaling limits as the grain size decreases with scaling. Hence their resistivity increases and grain boundary scattering occurs. Thus alternative technologies are required to meet the future challenges given by the International Technology Roadmap for Semiconductors (ITRS).

The ever increasing scaling of integrated circuits is making the interconnect technology a critical aspect in VLSI circuits. Novel integration mechanisms like 3D ICs, multi-core ICs, etc. to attain high speeds and miniaturisation to the core, give rise to reliability problems like thermal reliability, crosstalk, electromigration and scattering [13,26].

* Corresponding author. Tel.: +91 4162249815; fax: +91 4162243092.
E-mail address: psmallick@vit.ac.in (P.S. Mallick).

1878-7789/$ – see front matter
doi:10.1016/j.nancom.2012.09.004

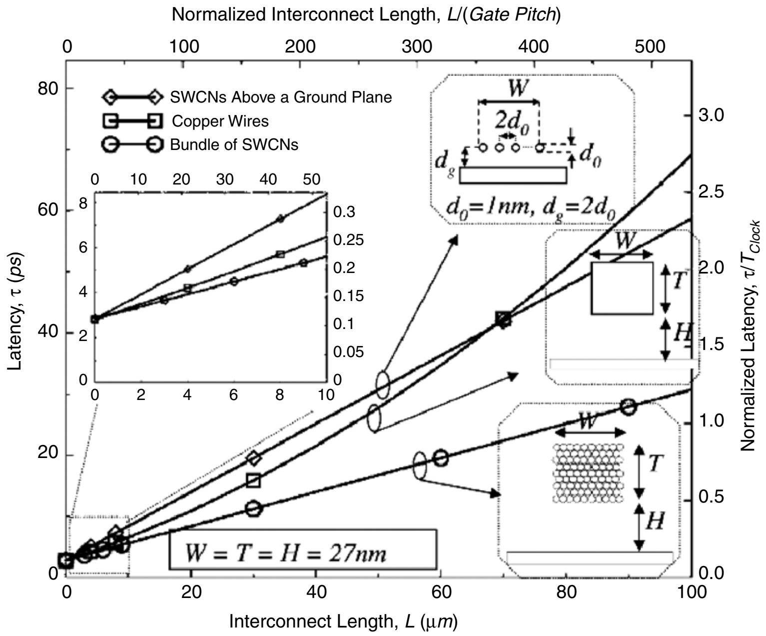

Fig. 1. Latency vs. interconnect length [27].

As the scaling goes beyond 22 nm, new materials that can achieve good performance and reliability are being introduced. They are quantum wires called carbon nanotubes. They have very large mean free paths up to a few micrometers at room temperatures, high current carrying capacity, resistance to electromigration, high thermal conductivity and ability to conduct at very high frequencies [26].

Single walled carbon nanotubes (SWCNTs) are one dimensional nanowires that are formed by the rolling up of graphene sheets. They are either conducting or semiconducting depending on their atomic structure, called chirality. Multi walled CNTs (MWCNTs), on the other hand, are concentric cylinders of CNTs that have different diameters and varying chiralities. Their unique properties of high electrical and thermal conductivity coupled with high tensile strength, ballistic transport at high frequencies and resistance to electro-migration have made them ideal for future nanoelectronics applications especially as interconnects in ICs and as channel material in FETs. The electrical and structural properties of CNTs were discussed by many authors [21,34].

In 2002, Cheung et al. [3] have grown CNTs by the CVD method and after analysing by TEM they have shown that the CNTs were basically in bundle form and a mixture of both SWCNTs and MWCNTs. These types of bundles are called mixed CNT bundles [9]. Mixed CNT bundles (MCBs) have received attention lately due to the advantages they have over SWCNTs and MWCNTs. So, it can be seen that interconnects made of mixed CNTs have superior performance and reliability than SWCNTs and MWCNTs.

Many reviews on CNT growth [33], CNT interconnects [26], CNTFET [32], etc. based on SWCNTs and MWCNTs were done. For the first time, we are reviewing the modelling, simulation and performance analysis of mixed CNT bundles. We also discuss the structural properties and hence the factors that govern the performance of mixed CNT bundle interconnects.

The rest of this paper is organised as follows. Section 2 overviews the circuit modelling of CNT interconnects that include SWCNTs and MWCNTs. Then, we discuss mixed CNT bundle technology for VLSI interconnects in Section 3. Modelling of MCB interconnects is done in Section 4. Crosstalk of CNT interconnects is discussed in Section 5. Finally we conclude this review in Section 6.

2. Overview of CNT interconnect technology

CNT interconnects were modelled based on the Luttinger liquid theory [2]. This theory describes how electrons interact with each other in one dimension. The electron is created by considering an infinite number of excited 1-D plasmons. Physically, this nature of electrons described by circuit modelling is done to extract the DC and impedance parameters of 1D interconnects. Hence the transmission line (TL) modelling was done. SWCNTs are considered as quantum wires and its equivalent TL parameters were found [2,27]. The resulting impedances and delays were compared with copper. It was found that SWCNTs have large resistances and hence, a bundle of CNTs are ideal as interconnects as shown in Fig. 1. The latency increase in SWCNTs is almost double compared to SWCNT bundles. Many geometries were proposed like monolayer interconnects [22]. As they possess 50% lesser capacitance than Cu, they can be used as short local interconnects which have large resistances though. Driver resistance dominates here.

The conductivity of CNTs is calculated using the Landauer–Buttiker formula:

$$G = (Ne^2/h)T \quad (1)$$