Electromagnetic Coupling to Nano-Devices: 2D vs. 1D

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Abstract **– This paper discusses the coupling of two dimensional and one dimensional nano-materials to electromagnetic waves across the spectrum, from RF to light wave.**

1 INTRODUCTION

There is general misconception and misunderstanding in the literature about the coupling of electromagnetic waves to nano-electronic devices. Researchers in the optical frequency domain pay most attention to relative coupling vs. e.g. wavelength, angle of incidence; thus, are most interested in the local enhancement of optical field strength, which allows for higher resolution in applications such as lithography than tradition imaging based system. With the exception of graphene, where the absolute absorption is given by the impedance mismatch between free space (Z_0 = 377 Ω) and the resistance quantum (h/e^2 or 25 kΩ), little attention is paid to the absolute cross section of nanoelectronics with light waves. In the RF, the situation is the opposite, in which most researchers pay attention to the absolute values (e.g. impedance, absorption, absolute scattering cross section). In the RF, the local enhancement of electric fields is trivial. In this talk we will compare and contrast these two approaches. Of particular interest is the poor coupling of one-dimensional nanostructures to electromagnetic waves (which persists throughout the entire frequency range, from RF to lightwave). In the two-dimensional case, the situation is much more interesting: While at optical, coupling is weak, in the THz and RF, it is possible to have a perfect impedance match to free space.

This is a review paper that synthesizes and combines prior knowledge in the field of electromagnetics and nanotechnology, and summarizes the state of the art as of 2015. For space reasons we do not focus on the imaginary (plasmonic, non-dissipative) aspect of the interaction. Rather, we focus on the dissipative (absorptive) coupling in this review.

2 ONE-DIMENSIONAL NANO-MATERIALS

One-dimensional materials, in the quantum mechanical sense, have dimensions comparable to the quantum mechanical wavelength of electrons. While this is easiest achieved with single walled carbon nanotubes, it can be achieved with other material systems as well. It has been know for many years that these have a DC resistance that is of order the resistance quantum. We next discuss how this behaves at AC.

2.1 RF to THz (1d)

We review the theory and experiment of RF to THz properties of one-dimensional materials.

2.1.1 RF to THz Theory (1d)

We[1][2], [3] have proposed that a one dimensional material in the RF and THz behaves as a quantum transmission line. This circuit characterization is backed up by more rigorous electromagnetic theory[4], [5]. The characteristic impedance of this transmission line is of order the resistance quantum, in contrast to classical transmission lines. The wave velocity is of order the Fermi velocity, which is about 100 times less than the wave velocity of light in free space and on classical transmission lines.

These behave as quantum transmission lines with very different behavior from classical transmission lines.

2.1.2 RF to THz Experiment (1d)

So far, direct evidence of wave propagation has been limited in the literature[6]. However, discrete elements such as the quantum capacitance[7] and kinetic inductance[8], [9] have been observed.

One of the challenges is measurement of high impedance devices at high frequencies. Progress in this area of measurement technology will benefit both the topic of this paper, as well as CMOS industry, which is increasingly concerned with fringe field capacitance in the nano-CMOS era.

2.2 Lightwave (1d)

2.2.1 Lightwave Theory (1d)

The theory of the interaction of lightwaves with carbon nanotubes has been explored [4], [5]. One simple, intriguing question has not been clearly answered in the literature: What is the absolute cross section of a one-dimensional material? In the lightwave, there is a strong frequency dependence if the optical photons have enough energy to excite an electron-hole pair. We speculate that a concise summary will show that the cross section per unit length will be equivalent to a wire with resistance

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