Design of Antenna Structures for Carbon Nanotube based Infrared Sensors with the Consideration of Quantum Behaviors in Field Enhancement

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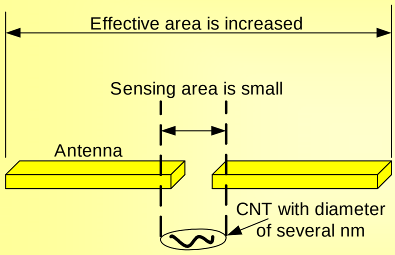
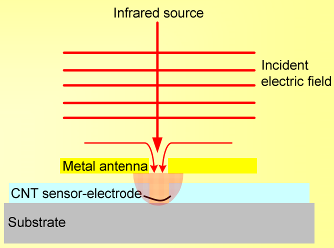
Motivation





⇒ In nano environment, an antenna is more efficient

⇒ The field in the vicinity of the dipole antenna is enhanced

Theoretical Analysis

Analysis: Quantum conductivity and near-field radiation from the antenna

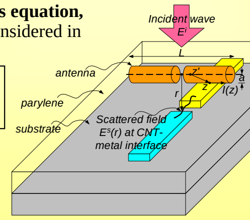
Incident infrared wave – $E^i(z)$ → *Quantum method* → **Current generated along the antenna – $I(z)$** → **Scattered wave – E^s**

$$\left(k^2+\frac{\partial^2}{\partial z^2}\right)\int_{-L}^{L}\frac{e^{-jk\sqrt{(z-z')^2+a^2}}}{\sqrt{(z-z')^2+a^2}}I(z')dz' = j4\pi\omega\varepsilon\left(\frac{1}{2\pi a\sigma}I(z)-E^i(z)\right)$$

$$E^s(r)=\frac{1}{j\omega\varepsilon}(k^2+\nabla\nabla\cdot)\int_V g(r,r')\,J(r')\,dV'$$

By applying **Schrödinger's equation**, quantum conductivity is considered in nano environment

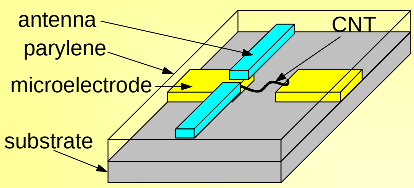
$$\sigma(\omega)=-j\frac{e^2E_F}{\pi\hbar^2(\omega-j\upsilon)}$$



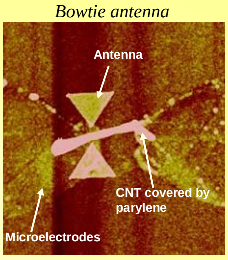
$\bar{\bar{G}}(r)$: **Layered medium Green's function**

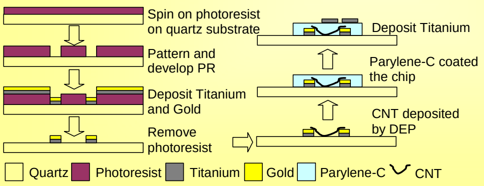
$$E^S=\bar{\bar{G}}(r)*J(r)$$

Design

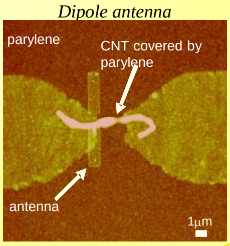


Bowtie antenna

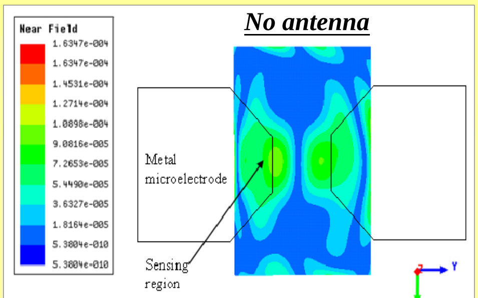




Dipole antenna

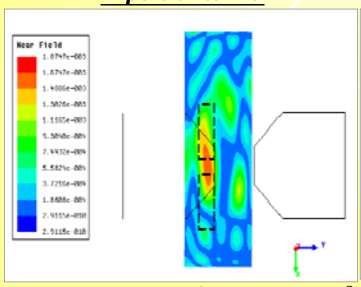


Theoretical Results



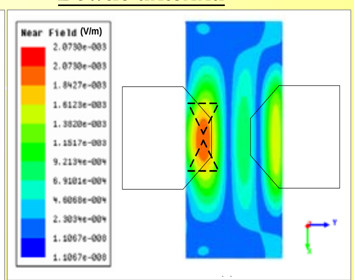
L=0; maximum electric field: ~1*10^{-4}

Dipole antenna



maximum electric field: ~1.6*10^{-3}

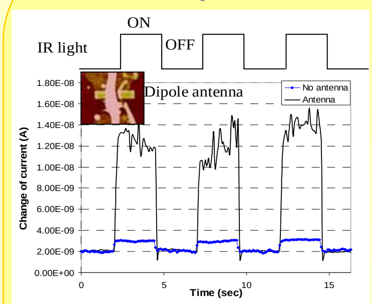
Bowtie antenna

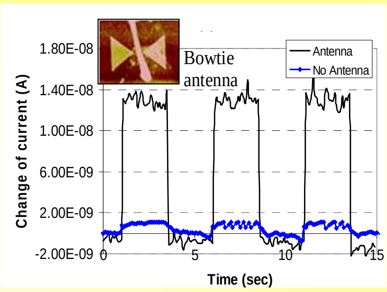


maximum electric field: ~2*10^{-3}

⇒ The bowtie antenna generates higher enhancement factor

Experimental Characterizations



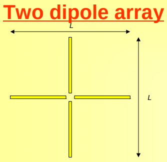


Type of antenna	Dimension of the antenna (LxWxH)	Photocurrent		Gain of the photocurrent
		Without antenna I_{pho}	With antenna I_{ph}	I_{ph}/I_{pho}
Antenna 1	5.6um x 1.4um x 30nm	1x10^{-9}	1.8x10^{-8}	10.8
Antenna 2	9.3um x 1.4um x 25nm	1.8x10^{-10}	1.1x10^{-9}	6.1
Antenna 3	5um x 1.1um x 40nm	3x10^{-9}	2.3x10^{-8}	7.6

⇒ Higher gain obtained from bowtie antenna - photocurrent is increased by ~14 times

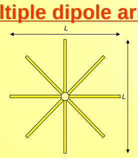
Future Design

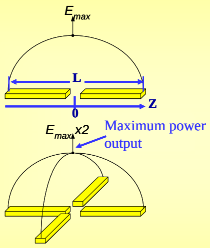
Two dipole array



⇒ *Estimated gain from theoretical calculations ~32*

Multiple dipole array

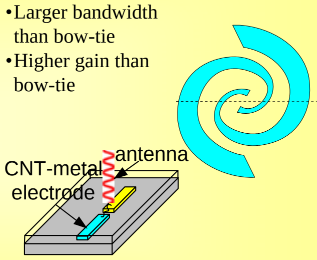




⇒ *Estimated gain from theoretical calculations ~64*

3D coil

- Larger bandwidth than bow-tie
- Higher gain than bow-tie



⇒ *Estimated gain from theoretical calculations ~160*