Light at Ambient Temperature

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***Abstract*-Over the past decade, extensive research on nano-materials has discovered many interesting properties, but the applications upon which mankind may benefit need to be explored. One potential benefit is to harness the thermal energy available in the ambient environment to produce artificial light. Light from the environment offers the advantage of significantly reducing the world-wide need for oil fired or nuclear power plants, at least for the production of lighting. To this end, nanoparticles (NPs) in a mix of microparticles (MPs) are proposed as light sources that by quantum electrodynamics (QED) convert the electromagnetic (EM) radiation in the blackbody (BB) surroundings at ambient temperature to visible (VIS) light . By the Mie theory, NPs and MPs partially absorb the long wavelength BB radiation but lacking specific heat cannot conserve the absorbed BB photons by an increase in temperature. Instead, the NPs and MPs are induced by QED to conserve the absorbed BB photon by increasing its frequency to their respective EM confinement frequencies - the process called QED induced EM radiation. Since the efficiency of converting BB radiation in NPs to VIS is very low, MPs in the mix first convert BB radiation to near infrared (IR) radiation prior to conversion to VIS light. But the VIS light from a single 100 nm NP is about 14 pW, so a large number of NPs are required to produce a 100 W light bulb. Extensions are made to unresolved problems in various areas of physics.**

I. INTRODUCTION

Perhaps the invention that has most benefited mankind is the electric lamp [1] by Edison that produced artificial light from the incandescence in passing electric current through a tungsten filament in an evacuated glass bulb. Prior to that time gas lamps were the common artificial light form evolving from oil burning wicks used around 50,000 BC.

Today, Edison's lamp is constantly being improved upon by recent discoveries in light emission by incandescence (IL), electroluminescence (EL), and photoluminescence (PL).

Closely related to the tungsten wire in the common electric bulb is the light produced from the IL in passing current [2] through filaments comprising carbon nanotubes (CNTs). Indeed, Edison's attempt to use carbon instead of metal filaments failed because carbon deposition at high filament temperatures darkened the glass. Recently, CNTs as a replacement for tungsten filaments have been shown [3] to avoid darkening provided any amorphous carbon and contaminants are removed. Light emission is not strictly IL in that spectral lines common to EL are observed.

However, light emission from nanoscale materials need not rely on CNTs producing light by IL and EL Recently, EL with electrodes and PL from electrode-free configurations have been reported. Depositing light-emitting polymer fibers on a silica substrate patterned with gold electrodes was found [4] to produce EL over an area of a few 100 nm upon applying voltage across the electrodes, the light a bright orange was located in a spot spanning the electrodes. In contrast, an electrode-free PL concept [5] used an infrared (IR) laser in the manner of optical tweezers to trap an individual inorganic nanowire that acts as a frequency converter through second harmonic generation to produce various colors of light. Of interest to microscopy, the nanowire may be moved over a sample to determine the variable frequency atomic response.

With IR lasers, a far simpler approach to producing a nanoscale PL source uses [6] quantum dots (QDs). Here, the QD is a NP. Even so, IL with CNTs, EL with electrodes, and PL with IR lasers in nanowires and QDs, all require a source of electrical power. Although nanotechnology has already made significant improvements over Edison's light bulb, nanotechnology has to go further, and if possible avoid the use of electrical power altogether. But the only form of EM radiation available is BB radiation that lacks the Planck energy to produce VIS light.

II. PURPOSE

The purpose of this paper is to consider a light bulb comprising a large number of NPs and MPs in a miniature glass bulb that by QED induces frequency up-conversion of BB radiation to VIS light.

III. THEORY

Currently, QD theory [6] is not sufficiently understood to explain the significant increase in VIS light produced under near IR (NIR) laser irradiation. In the alternative, QED induced EM radiation [7, 8] creates photons of a prescribed frequency by supplying EM energy to a confined space of NP dimensions. A QD of diameter D irradiated by a NIR laser and emitting VIS light is shown in Fig. 1.

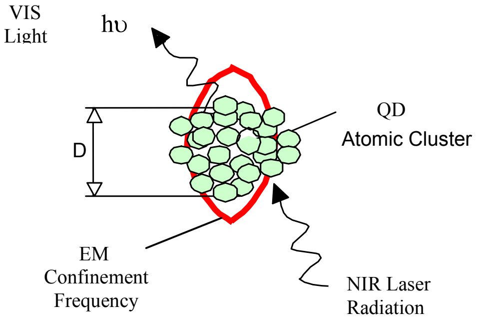

Figure 1 QED induced EM radiation in QDs

The EM confinement frequency f and wavelength λ of the QED induced photons are,

$$f = \frac{c}{\lambda} \quad \text{and} \quad \lambda = 2Dn_r \tag{1}$$

where, n_r is the refractive index of the QD. The Planck energy E_p of the QED induced photons is,

$$E_p = \frac{hc}{2Dn_r} \tag{2}$$

How the QD conserves the absorbed NIR radiation is somewhat controversial. One conservation path is by an increase in temperature. But this path is blocked. To show this, consider the Einstein-Hopf relation [9] for the harmonic oscillator shown at T = 300 K in Fig. 2.

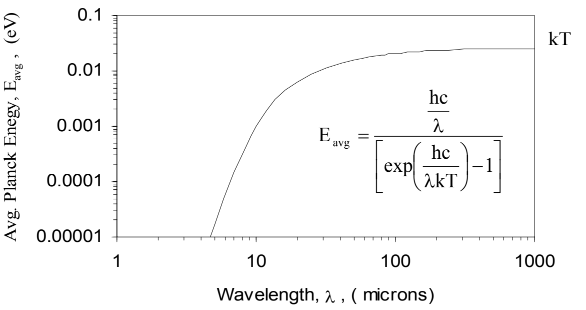

Figure 2 – Planck Energy of Harmonic Oscillator at 300K.
In the inset, h is Planck's constant, k is Boltzmann's constant, c is the speed of light, and T is absolute temperature.

Consider the QD to be an Einstein solid comprised of N_A atoms represented by harmonic oscillators for each degree of freedom. For $N_{dof} = 3$, the total energy U is,

$$U = 3N_A \frac{\frac{hc}{\lambda}}{\left[\exp\left(\frac{hc}{\lambda kT}\right)-1\right]} \tag{3}$$

The specific heat C is,

$$C = \frac{\partial U}{\partial T} \tag{4}$$

giving the dimensionless specific heat C*,

$$C^* = \frac{C}{3N_A k} = \frac{\left(\frac{hc}{\lambda kT}\right)^2 \exp\left[\frac{hc}{\lambda kT}\right]}{\left[\exp\left(\frac{hc}{\lambda kT}\right)-1\right]} \tag{5}$$

The dependence of C* on frequency $f = c / \lambda$ may be understood by the oscillation of absorbed NIR photon at the EM confinement frequency of the QD. At 300K, the C* variation with QD diameter is shown in Fig. 3. The absorbed NIR radiation is conserved by an increase in temperature for diameters D > 4 microns and otherwise by the emission of EM radiation. In this way, QED induces high frequency EM radiation that in QDs is emitted as VIS light.

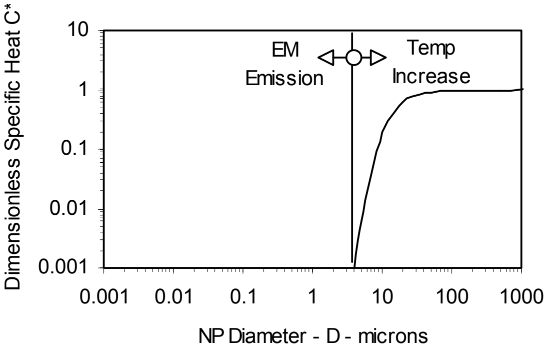

Figure 3 Dimensionless Specific Heat C* v QD Diameter

By Mie theory, QDs having diameters D far smaller than the NIR laser wavelength at least partially absorb [10] the incident flux F of NIR radiation. The absorbed EM energy Q_{Mie},

$$Q_{Mie} = \frac{\pi D^2}{4} Q_{abs} F \tag{6}$$

where, the laser flux F is assumed to irradiate the QD only from one side, and Q_{abs} is the Mie absorption efficiency. For NPs smaller [11] than the wavelength λ ,

$$Q_{abs} = 4X \,\mathrm{Im}\left(\frac{m^2 - 1}{m^2 + 2}\right) \tag{7}$$

where, X is the size parameter, $X = 2\pi R/ \lambda$, and m is the complex refractive index, m = a - b i. Hence,

$$Q_{abs} = \frac{48\pi abR / \lambda}{\left(a^2 + b^2 + 2\right)^2 + 4a^2b^2} \tag{8}$$

For QDs, the absorption efficiency Q_{abs} in converting NIR at 800 nm to VIS at 400 to 600 nm may be considered unity. Moreover, only a single interaction between the NIR and the NP is required in the conversion.

Similar to creating a photon by supplying EM energy to a box having sides separated by the half-wavelength of the photon, the EM energy of the absorbed NIR laser photon in a QD is conserved by an increasing its frequency to the EM confinement frequency of the NP, thereby inducing Planck energy far in excess of the typical semiconductor band-gaps. Excitons are created [7,8] in proportion to the Planck energy, thereby exceeding the 1 photon – 1 exciton rule for the bulk.

IV. ANALYSIS

In the ambient environment, there are no IR lasers, only BB radiation. Regardless, Mie theory for QDs may be extended to the absorption of BB radiation by NPs by treating BB radiation as a broadband IR laser with a central peak at about 10 microns. For BB radiation irradiating the NP from all sides,

$$F = \sigma T_{BB}^4 \quad \text{and} \quad Q_{Mie} = \pi\sigma D^2 T_{BB}^4 Q_{abs} \tag{9}$$

In contrast to QDs under NIR lasers, the Mie efficiency Q_{abs} is low for a NP absorbing IR radiation at 10 microns in a single interaction. However, with multiple interactions between MPs of a prescribed size, VIS light may be efficiently produced. For Metoxides with a refractive index $n_r \sim 1.2$, the IR at 10 microns is first converted to mid-IR at 2 microns in 0.833 micron NPs, then the mid-IR at 2 microns is converted to near-IR at 0.75 microns in 0.31 micron NPs, and finally the 0.75 near IR is converted to VIS light at 0.31 micron in 0.13 micron NPs. Fig.4 is based on Eqn. 8 to convert IR at 10 microns to VIS light for unity Q_{abs} in NPs of aluminum and metal oxides.

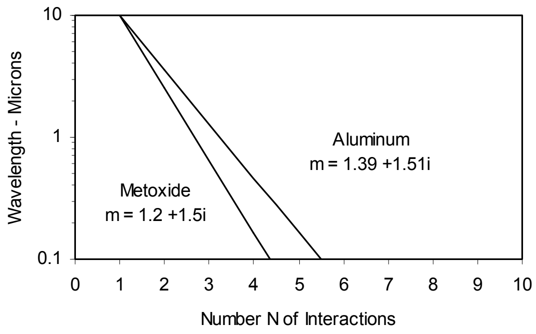

Figure 4 QED Conversion of IR to VIS Light

In contrast, the Stefan-Boltzmann (S-B) equation for radiative heat Q_{SB} transfer implicitly assumes unity Q_{abs},

$$\frac{Q_{SB}}{A} = \sigma\left(T_{BB}^4 - T^4\right) \tag{10}$$

where, σ is the S-B constant, A is NP area, and T and T_{BB} are the temperatures of the NP and BB surroundings.

Beyond excluding Mie absorption efficiency, the S-B equation assumes the NP has specific heat to conserve the absorbed BB radiation by an increase in temperature T. But NPs lack specific heat and may only conserve the absorbed BB radiation by the emission of QED induced EM radiation. The modified S-B equation,

$$Q_{SB} = \overset{\text{Mie Absorption}}{\sigma A Q_{abs} T_{BB}^4} - \overset{\text{EM Emission}}{E_p \frac{dN_p}{dt}} \tag{11}$$

where, dN_P/dt is the rate of QED induced photons having Planck energy E_P.

The BB photon is absorbed, but the temperature of the particle cannot increase because of zero specific heat. In time, the NPs lose heat by radiation and the thermal kT energy decreases because heat is always lost, but never gained. At steady state, $Q_{SB} = 0$ at which time the absorbed Mie radiation is then directly converted to EM radiation. The rate of QED photons produced is,

$$\frac{dN_P}{dt} = \frac{Q_{Mie}}{E_P} = \frac{2\pi\sigma T_o^4 D^3}{hc} Q_{abs} \tag{12}$$

In a mix of NPs and MPs, the overall Mie efficiency Q_{abs} between a NP and the BB radiation may be taken as unity, thereby coinciding with the S-B relation for absorption. The QED photons having Planck energy E_p and production rate dN_P/dt at temperatures of 300 and 2.7 K are shown in Fig. 5.

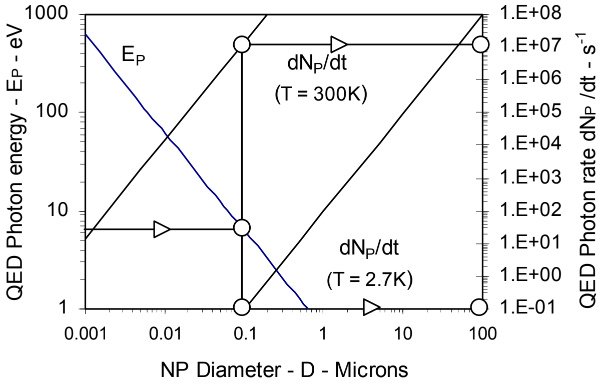

Figure 5 QED Photons at 300 and 2.7 K for Single NP

At an ambient temperature of 300 K, about 10^7 UV photons having Planck energy of 6.21 eV are produced every second in a single 0.1 micron diameter NP in a mix of NPs and MPs. The lighting power P is,

$$P = N_P Q_{Mie} = \pi\sigma D^2 T_{BB}^4 Q_{abs} N_P \tag{13}$$

where, N_P is the number of NPs. A single NP produces about 14 pW, and therefore about $N_P = 7\times10^{12}$ NPs are required for a P = 100 W light bulb. However, the NPs require attention in packaging to assure that the NPs do not agglomerate and lower the EM confinement frequency, say by embedding the NPs and MPs in a lossless dielectric. Fig. 6 depicts a 5 mm diameter 100 W miniature light bulb comprising a mix of NPs and MPs.

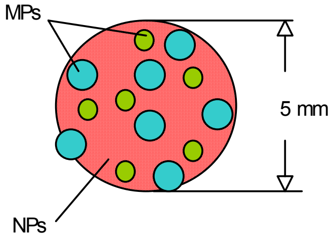

Figure 6 Light at Ambient Temperature
100 nm NPs on 200 nm spacing mixed with MPs in a lossless dielectric

Fig. 7 shows coating the outside surface of conventional light bulbs with a mix of NPs and MPs may offer the advantage of converting the waste heat into additional light.

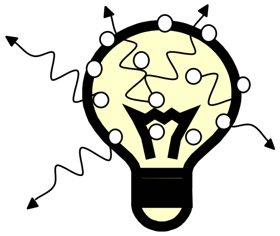

Figure 7 NP and MP Mixture Coating for Conventional Light Bulbs

V. EXTENSIONS

Extensions of QED induced EM radiation to areas of physics under laser irradiation are far more pronounced because of the high intensity of IR lasers compared to low level BB radiation.

A. Porous silica and Raman spectroscopy

The enhancement of response to IR laser excitation of surfaces is caused by the ubiquitous presence of NPs, e.g., porous silica [12] and surface enhanced Raman spectroscopy [13]. Mie theory assures at least partial absorption at high Planck energy by NPs not possible otherwise from surfaces.

B. Multi-photon response of molecules

Higher energy states of molecules are thought [14] excited by the addition of IR photons even though the probability of such a combination is extremely unlikely. With QED induced EM radiation, the molecule like a NP absorbs IR radiation and after filling lower quantum states excites the higher energy states. An increase in temperature does not occur to justify thermal statistical processes.

C. Laser induced incandescence

Measurement of NP size in the exhaust of diesel engines [15] is based on the cooling rate following laser induced incandescence (LII). But NP measurements are questionable as only particles greater than about 4 microns increase in temperature. Instead, the NP concentration may be inferred [16] from EM emission in the VIS and UV.

D. Cancer Therapy

Necrosis of cancer cells with preferentially attached NPs under NIR radiation is generally thought to occur by high NP temperatures. But the NPs lacking specific heat cannot conserve the absorbed NIR photons by an increase in temperature, and therefore the cancer cells are actually killed by EM radiation [17] in the UV and beyond. Extensions may be made to cancer therapy of interior body organs from EM radiation induced by magnetic NPs.

E. Nanofluids and Chemiluminescence

Over the past decade, nanofluids comprising NPs in solvents have been proposed to increase thermal conductivity far beyond long-standing mixing rules. But the increase is only apparent. NPs do convert BB radiation to VUV that after absorption in adjacent solvent acts as a weak heat source [18] to slightly increase apparent conductivities in hot-wire tests. That NPs as heat sources are a source of error in hot–wire tests is supported by greatly enhanced conductivity of nanofluids under laser irradiations. Similarly, BB radiation in NPs is expected to produce weak VUV sources that enhance chemiluminescence in the luminol-H_2O_2 reaction.

F. Interstellar Medium Lights

Of interest in astronomy is the interstellar medium (ISM) lights shown in Fig. 8. Both NPs and MPs are known to permeate the ISM, thereby suggesting the ISM lights are caused [19] by Mie absorption and QED induced EM emissions from dust particles in the BB surroundings at 2.7 K. Because of the continuous size variation in cosmic dust, the Mie efficiency Q_{abs} is taken as unity. Fig. 5 shows about one UV photons is produced every 0.1 second at 2.7 K, or 1 every 10 seconds. Current theory [20] predicts only one UV photon every 24 hours.

Figure 8 ISM Lights by Cosmic Dust

REFERENCES

[1] T. A. Edison, "An Improvement in Electric Lamps," U. S. Patent 223,898, 1880.

[2] P. Li, K. L. Jiang, M. Liu, Q. Q. Li, S. S. Fan, and J. L. Sun, " Polarized incandescent light emission from carbon nanotubes," *App. Phys. Lett.*, Vol. 82, pp. 1763 -5, 2003.

[3] K. Wei, H. Zhu, and D. Wu, "Carbon nanotube filaments in household light bulbs," *App. Phys. Lett.*, Vol. 84, pp. 4869-71, 2004.

[4] P. Patel-Predd, "Tiny Light Bulbs," MIT Technology Review, April 18, 2007.

[5] Y. Nakayama, et al., "Tunable nanowire nonlinear optical probe," *Nature*, Vol. 447, pp. 1098-1103, 2007.

[6] V. I. Klimov, "Mechanisms for Photogeneration and Recombination of Multiexcitons in Semiconductor Nanocrystals: Implications for Lasing and Solar Energy Conversion," *J. Phys. Chem. B*, 110, pp. 16827-45, 2006.

[7] T. V. Prevenslik, "Quantum Dots by QED," International Conference on Materials for Advanced Technologies (ICMAT), July 2-6, Singapore, 2007.

[8] T. Prevenslik, "Quantum Dots and QED," Materials Science & Technology 2007 Conference (MS&T 2007), COBO Center, Detroit, September 16-20, 2007.

[9] R. W. Christy and A. Pytte, *The Structure of Matter: Introduction to Modern Physics*, Benjamin, New York, 1965.

[10] G. Mie, Beiträge zur Optik trüber Medien, speziell kolloidaler Metallösungen, Leipzig, *Ann. Phys.*, Vol. 330, pp. 377–445, 1908.

[11] C. F. Bohren and D. R. Huffman, *Absorption and Scattering of Light by Small Particles*, J. Wiley & Sons, 1983.

[12] L. T. Canham, "Silicon quantum wire array fabrication electrochemical and chemical dissolution wafers," *Appl. Phys. Lett.* Vol. 57, pp. 1046, 1990.

[13] A. Campion and P Kambhampati, "Surface-enhanced Raman scattering," *Chem. Soc. Rev.*, Vol. 27, pp. 241-50, 1998.

[14] E. R. Grant, P. A. Schulz, As. S. Sudbo, Y. R. Shen, and Y. T. Lee, "Is Multiphoton Dissociation of Molecules a Statistical Thermal Process?" *Phys. Rev. Lett.*, 40, pp. 115-8, 1978.

[15] L. A. Melton, "Soot Diagnostics Based on Laser Heating," *Appl. Optics*, Vol. 23, pp. 2201- 2208, 1984.

[16] T. V. Prevenslik, "Laser Induced Incandescence and Particle Size ," Proc. 5th Int. Conf. on Heat Transfer and Thermal Engineering and Environment, Athens, August 25-27, pp. 216-9, 2007.

[17] T. V. Prevenslik, "Nanoparticles in Cancer Therapy," Presented at ICMAT, July 2-6, Singapore, 2007.

[18] T. .Prevenslik, "Nanofluids-Enhanced Thermal Conductivity or Heating?" To be Published.

[19] T. Prevenslik, "ISM Spectrum by Cosmic Dust? To be published.

[20] A. N. Witt, *J. Geophys. Res. Phy.*, "Small and Very Small Interstellar Grains," Vol. 105, A5, pp. 10299-303, 2000.