Lighting at Ambient Temperature

Thomas Prevenslik
QED Radiations-Berlin, Germany

Abstract

The Carnot efficiency of a heat engine operating between hot and cold reservoirs implicitly assumes some heat to always be loss to the surroundings thereby precluding converting heat directly into work. Over 200 years, the Carnot limit based on classical physics implies 100% efficiency is only possible if all thermal energy is removed which can only occur if the cold reservoir is at absolute zero. Although valid for the common heat engine, the Carnot limit of classical physics is not applicable to microscopic heat engines governed by the Planck law of quantum mechanics which denies the atom under high EM confinement the heat capacity to conserve heat by a change in temperature, i.e., a 100% Carnot efficiency is possible, but does not depend on temperature of the cold reservoir. Indeed, heat transfer at the nanoscale by simple QED theory conserves heat by the emission of EM radiation instead of a temperature change. By simple QED, microscopic heat engines remove all thermal energy and directly convert heat to work at 100% Carnot efficiency by emitting EM radiation in the form of non-thermal photons. Application of simple QED shows converting heat from the ambient 20 °C temperature environment in a 2 cm^2 silicon surface decorated with a pattern of laser induced 140 nm bottom truncated spherical nanoparticles can produce small 50 W patches emitting green light at 580 nm powered only by natural convection.

I. Introduction

The Carnot efficiency of a heat engine operating between a hot reservoir at temperature T_H and a cold reservoir at temperature T_C is illustrated in Fig. 1.

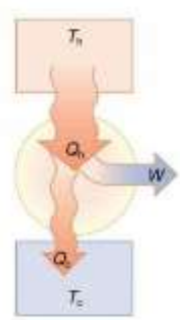

Figure 1. Carnot Heat Engine

The Carnot efficiency η of the heat engine is given by,

$$\eta = \frac{Q_H - Q_C}{Q_H} = \frac{T_H - T_C}{T_H}$$

where T_H and T_c are in Kelvins. Typically, the Carnot efficiency is η ~ 0.7. An efficiency η = 1 requires T_c = 0 K, or the cold reservoir is at absolute zero which is considered impossible. The only way to have all heat Q_H go into doing work W is to remove all thermal energy which requires a cold reservoir with a temperature T_C at absolute zero.

Over 200 years, the Carnot efficiency has characterized the heat engine. Recently, the applicability of the Carnot efficiency to microscopic heat engines has gained the attention of researchers. In a quantum cooled refrigerator, a quantum mechanics (QM) instead of classical physics is proposed [2] that shows photons providing the power to approach absolute zero temperature, but require a cooling rate proportional to the cold bath temperature. However, both the QM and classical Carnot models depend on the temperature T_C of the cold reservoir, a condition that may not exist at the quantum level because temperature does not exist. Similarly, quantum heat engines [3] working within the framework of quantum thermodynamics have shown negative heat capacity of the reservoirs produce Carnot efficiencies greater than the Carnot efficiency. Again, the problematic temperature T_C of the cold reservoir at the microscale remains. Even so, low-temperature (<100°C) heat sources [4] have the potential to provide renewable and clean energy, but are not economic. EM radiation permits semiconductor light-emitting diodes (LEDs) to emit more optical power (5,6) than the electrical power consumed thereby converting lattice heat to more energy efficient lighting.

LEDs are optical heat pumps that cool surroundings by converting heat from < 100 °C temperature reservoirs into IR photons. The energy of LED photons is given by the voltage to make an electron–hole pair, but does not affect the photon energy that depends on the band gap of the material. However, it is possible for the individual emitted photons to have energies that are different to the band gap. The vast majority of recombined electron–holes do not produce IR photons, but rather waste heat that boosts the energy [6] of photons produced by radiative recombination.

However, the conversion of waste heat to photons does indeed violate the second law of thermodynamics as photons are work - not heat as proposed in [6]. Photons upon colliding with an object create a pressure force that as work move the object. In fact, LEDs have never been shown to actually cool the surroundings. Tests showed [6] heating the LED to 135 °C at very low voltage produced 70 pW of emitted IR radiation while only 30 pW was consumed giving an efficiency η > 200%. What this means is the waste heat from electron-hole combination is insignificant and the 135 °C heating alone is the source of increased efficiency. A direct conversion of heat (135 °C + electron-hole waste) to work (photons) without a need for a cold T_C reservoir is suggested that does indeed satisfy the second law. Another mechanism directly converting heat to light is suggested.

Similarly, laser-induced heating of submicron films of silicon nanocrystals (NC) embedded in SiO2 separated by pure SiO2 spacers were found [7] to increase threefold the radiative emission rate. The mechanism of observed enhancement is claimed to be the significant phonon production under laser stimulation. However, the Planck law denies the atoms in the submicron films the heat capacity to increase in temperature, and therefore the production of phonons cannot occur. Again, another mechanism is enhancing the emission. But the question remains:

How does heat directly produce photons?

II. Purpose

Apply simple QED theory [8] of nanoscale heat transfer to a single nanoparticle (NP) as the microscopic heat engine. Unlike classical heat transfer, simple QED based on the Planck law avoids the classical requirement of the cold reservoir at absolute zero to allow heat from the hot reservoir to be 100% converted to light at ambient temperature. Apply simple QED to the feasibility of small 2 cm^2 patches providing 50 W of visible light. The frontal patch surface is a silicon film decorated with a laser induced pattern of 140 nm bottom truncated spherical NPs heated by the natural convection of ambient air, the back surface provided with a sticky material for attaching to room walls.

III. Analysis

Simple QED is a nanoscale heat transfer process based on the Planck law of QM differing from that of classical physics, an early version of which in relation to the conversion of heat to light is given in [9]. Over the past decades, research in nanoscale heat transfer has advanced, but there are still challenges in understanding the mechanism of nanoscale thermal transport. Perhaps, researchers have not appreciated the significant difference between classical physics and the Planck law with regard to the heat capacity [10] of the atom at 300 K as illustrated in Fig. 2.

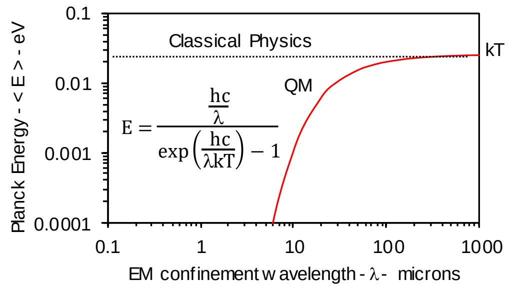

Figure. 2: Planck law of the Atom at 300 °K
In the inset, E is Planck energy, h Planck's constant, c light speed, k Boltzmann's constant, T absolute temperature, and λ the EM wavelength.

The Planck law at 300 K shows classical physics allows the atom constant kT heat capacity over all EM confinement wavelengths λ. QM differs as the heat capacity of the atom decreases for $\lambda < 200$ microns, and vanishes at the nanoscale for $\lambda < 100$ nm. Indeed, the Planck law denies atoms in nanostructures the heat capacity to change temperature upon the absorption of heat - a difficult notion to accept because of our training in classical physics. QM requires heat transfer to occur without changes in temperature.

Simple QED is a method of nanoscale heat transfer analysis that conserves heat with EM radiation instead of temperature. Here, QED stands for quantum electrodynamics, a complex theory based on *virtual* photons advanced by Feynman and others. In contrast, simple QED is a far simpler theory based on the Planck law that only requires the heat capacity of the atoms in nanostructures to vanish allowing conservation to proceed by the creation of *rea*l photons comprising EM waves that stand within and across the nanostructure.

Similar to electron level quantum states, simple QED quantum states are size dependent based on the dimension of the nanostructure over which the EM waves stand. But brief EM confinement of absorbed heat Q at the surface is necessary to form EM waves. Earlier EM confinement assumed the inwardly disposed heat Q over the surface was absorbed in a penetration depth δ before forming the standing wave, but this takes time. In this paper, the momentum of the inward heat Q flux as a Poynting vector is proposed to provide a simpler, yet spontaneous EM confinement that forms the standing wave across the diameter d of a NP as shown in Fig. 3.

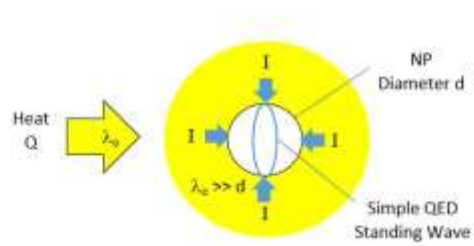

Figure 3. Brief momentum EM confinement

Importantly, the inward disposed Poynting vector is a consequence of the NP be immersed in the heat Q which may be considered FIR radiation having wavelength λ_o, where $\lambda_o >> d$ as illustrated with heat Q (yellow) immersing the NP shown in Fig. 3. Since heat Q cannot be conserved by a change in temperature, conservation proceeds by the creation of simple QED radiation in the form of non-thermal standing waves within the geometry of the NP.

The spherically symmetric inward momentum flux I of the incident heat Q acts as the Poynting vector S = Q/c giving $I = \pi d^2 S\Delta t = \pi d^2 Q\Delta t/c$, where Δt is the duration of Q. But the momentum flux p of N_p photons standing in the NP is, $p = N_p \cdot h/\lambda$, where λ is the wavelength of simple QED radiation. For $Np \cdot E = \pi d^2 Q\Delta t$, $I = N_p \cdot E/c = N_p \cdot h/\lambda$. Hence, brief EM confinement requires I > p, but thereafter Q vanishes and p > I allowing the standing EM radiation to be emitted to the surrounding.

The Planck energy E of a photon in the NP is given by the time τ required for light to travel across and back the NP diameter, $\tau = 2d/(c/n)$, where n is the index of refraction of the NP. Hence, the Planck energy E of the simple QED photons is, $E \sim h/\tau = hc/2nd$ giving the wavelength $\lambda = 2nd$, or

$$E = \frac{hc}{2nd}$$

IV. APPLICATION

A. Simple QED

Of interest is the application of simple QED to silicon NPs to laser induced fabrication of patterned arrangements of NPs in production [11] of lighting devices. Bottom truncated spherical silicon shapes d/2 are formed on silicon substrate dt on a quartz plate. The simple QED wave stands between an average height as shown in Fig. 4.

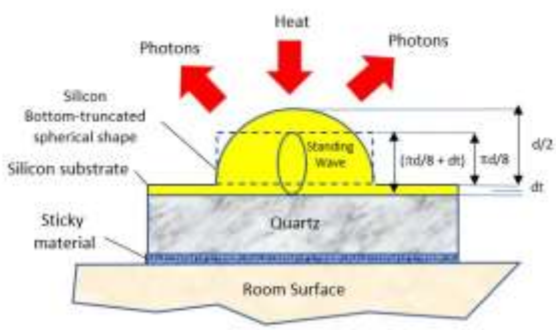

Figure 4. Bottom-truncated spherical shape

The pattern of truncated shapes and the corresponding Reflection Spectrum is shown in Fig.5.

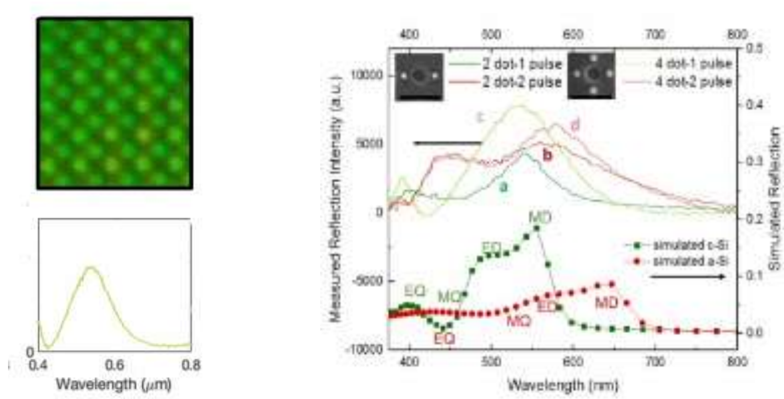

Figure 5. Laser induced pattern and Reflection Response

Specifically, silicon d = 140 nm NPs are formed [12] on the silicon substrate. The simple QED wave stands over an averaged ($\pi d/8 + dt$) height above the quartz surface. The silicon substrate dt thickness is 20-25 nm. Fig. 5 shows the peak Reflectance Spectrum response for c - 4 dot-1 pulse to occur at about 550 nm. For amorphous silicon [12], the refractive index n = 4.36 at λ = 550 nm. Hence, the silicon substrate thickness dt = ($\lambda/2n - \pi d/8$) = 6.5 nm. But dt << 20-25 nm suggests the silicon may be crystalline. Indeed, the refractive index n = 4.073 at 550 nm for crystal silicon [13] gives dt = 12.5 nm, but still not 20-25 nm.

Alternatively, consider a peak Reflection Spectrum response for the d - 4 dot-2 pulse at about 580 nm shown in Fig. 5. For amorphous and crystal silicon, the refractive indices 4.32 and 3.99 give dt = 12.2 and 17.7 nm, respectively. By taking d = 130 nm NPs, the amorphous and crystal silicon gives dt = 16.0 and 21.6. Hence, simple QED for a 130 nm NP having a peak at 580 nm is consistent with [11] data.

B. Ambient Temperature Light

Consider a light source comprising a laser induced pattern [11] of 140 nm silicon NPs exposed to ambient air at 20 °C that by natural convection emit 50 W of green light at 580 nm. The 140 nm NPs are spaced at a pitch p = 400 nm.

Fig. 4 allows the area A of d = 140 nm truncated NPs on a pitch p = 400 nm exposed to ambient air over area A is, $A = (\pi d^2/4 + p^2)$ giving $A = 1.75 \times 10^{-13}$ m^2. At atmospheric pressure, the natural convection heat transfer coefficient HC of 250 nm wires is H_C = 4000 W/km2 as shown in Fig. 6.

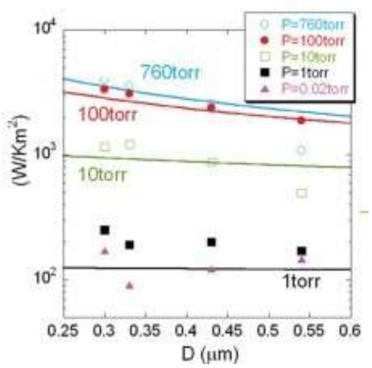

Figure 6. Convection heat transfer coefficient from sub-micron wires in air

Since the Planck law denies the NP temperature, the effective temperature is absolute zero. Hence, the temperature difference ΔT is 300 K giving the heat Q absorbed as, $Q = H_C A \Delta T$ = 22.8 nW. The number N of truncated NPs in a 2 cm^2 area of the patterned NP array is, $N = 2.3 \times 10^9$ giving a light power of about 50 W.

V. CONCLUSIONS

The classical Carnot heat engine cannot be 100% efficient as some heat is always loss to the surroundings. 100% conversion of heat Q_H from the hot reservoir at temperature T_H to work W requires a cold reservoir temperature T_C of absolute zero.

Microscopic Carnot engines governed by the Planck law avoid the absolute zero requirement of classical physics to allow 100% efficiency by denying the atom under high EM confinement the heat capacity to conserve heat by a change in temperature. Instead, heat is conserved by directly producing work in the emission of EM radiation or photons.

Laser enhanced decoration of 130-140 nm bottom truncated silicon NPs on small 2 cm^2 silicon films are shown by simple QED to support the fabrication of small 50 W surfaces emitting 580 nm green-light powered only by natural convection from air at 20°C.

The classical notion that in order to turn heat into red-light a metal needs to be heated to approximately 2000 K is superseded by simple QED under natural convection in air at 20° C.

The enhanced efficiency of heating the LEDs to 135 °C is caused by the simple QED conversion of heat to work in the form of photons without a need for a cold T_C reservoir that does indeed satisfy the second law.

Laser-induced heating of submicron films of silicon nanocrystals embedded in SiO2 separated by pure SiO2 spacers found to increase the radiative emission cannot depend on temperature dependent phonon production as the Planck law denies the existence of temperature at the nanoscale.

References

1. Lumen - Physics (2020) Carnot's Perfect Heat Engine: The Second Law of Thermodynamics Restated. https://courses.lumenlearning.com/physics/chapter/15-4-carnots-perfect-heat-engine-the-second-law-of-thermodynamics-restated/
2. Kosloff R., et al. (2000) Quantum refrigerators in quest of the absolute zero. J Appl. Phys. 87: 8093-8097.
3. Ma T-H. (2020) Effect of Finite-Size Heat Source's Heat Capacity on the Efficiency of Heat Engine. Entropy 22: 1002
4. Brogioli D., La Mantia F. (2018) Heat recovery in energy production from low temperature heat sources. AIChE
doi: 10.1002/aic.16496.
5. Santhanam P., et al. (2012) Thermoelectrically Pumped Light-Emitting Diodes Operating above Unity Efficiency. PRL 108, 097403.
6. Wogan T. (2012) LED converts heat into light. https://physicsworld.com/a/led-converts-heat-into-light/#:~:text=A%20light%2Demitting%20diode%20(LED,by%20researchers%20in%20the%20US. March 2.
7. de Jong E. MJD., et al. (2018) Thermally stimulated exciton emission in Si nanocrystals.
Light: Science & Applications 7: 17133.
8. Prevenslik T. (2021) Simple QED Theory and Applications. https://nanoqed.org, 2015-2021.
9. Prevenslik T. (2014) QED provides the world record 100 % conversion of heat to electricity, https://www.prlog.org/12333252-qed-provides-the-world-record-100-conversion-of-heat-to-electricity.html - June 7.
10. Planck M., "On the Theory of the Energy Distribution Law of the Normal Spectrum," Verhandl. Dtsch. Phys. Ges., Vol. 2, pp. 2-37, 1900.
11. Wang L., et al. (2018) Programming Nanoparticles in Multiscale: Optically Modulated Assembly and Phase Switching of Silicon Nanoparticle Array. ACS Nano 12: 2231–2241.
12. Pierce D.T. Refractive Index Info. See https://refractiveindex.info/tmp/data/main/Si/Pierce.txt
13. Filmetrics - Refractive Index of Si, Silicon. See https://www.filmetrics.com/refractive-index-database/Si/Silicon#:~:text=For%20a%20typical%20sample%20of,refractive%20index%20and%20extinction%20coefficients.
14. Cheng C., et al. (2012) Heat Transfer across the Interface between Nanoscale Solids and Gas.
ACS Nano 5:10102–10107.