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QED RADIATION – THE FOURTH MODE OF HEAT TRANSFER?

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ABSTRACT

Heat transfer may proceed by three modes: conduction, radiation, and convection. Conduction and radiation depend on the thermal properties of the material. Convection differs in that heat transfer depends on the properties of the fluid adjacent the material surface. However, heat transfer may also proceed by a fourth mode. Like convection altering the surface of the material, the fourth mode of heat transfer requires coating the surface of the material with a nanoscale layer of a material having a higher refractive index. Unlike conduction, radiation, and convection that find basis in classical physics, the fourth mode is based on QM with the heat transferred to the surroundings by EM radiation. QM stands for quantum mechanics and EM for electromagnetic. Classical physics that requires the atom to always have heat capacity does not predict any heat transfer enhancement for nanoscale coatings. But QM by requiring the heat capacity of the atom in nanoscale coatings to vanish precludes the conservation of heat by the usual increase in temperature. Instead, the heat into the coating under TIR is induced by QED to create non-thermal EM radiation that produces excitons (holon and electron pairs) that upon recombination emit the heat as EM radiation to the surroundings. TIR stands for total internal reflection and QED for quantum electrodynamics. Potential economic benefits of QED radiation to society are discussed that utilize nanoscale coatings to enhance the cooling of electronics circuit elements and gas turbine blades. However, QED radiation has non-economic benefits, say in cosmology by providing man with the knowledge the Universe in which he lives may not be expanding.

KEY WORDS: Thermodynamics, Electronic equipment cooling, Gas turbine blades, Cosmology, Quantum mechanics, Quantum electrodynamics

1. INTRODUCTION

Classically, heat transfer proceeds by conduction, convection, and radiation of which conduction is the most efficient. Conduction and radiation follow the laws of Fourier and Stefan-Boltzmann while convection transfers heat to a fluid by the Navier-Stokes equation. Finding origin in QM, QED heat transfer differs from classical physics by providing far more efficient cooling, but like convection requires surface modification by providing a coating having nanoscale thickness

Why does QED heat transfer require the coatings to be nanoscale?

Enhanced heat transfer by providing nanoscale coatings does not seem intuitively correct. Indeed, a recent review [1] of convective heat transfer between a solid and a fluid showed coating a surface with a porous metal increased the heat transfer area at the micron scale, but at the nanoscale little enhancement is expected. However, recent experiments [2] contradict the argument that little heat transfer enhancement should be expected with nanoscale porous coatings. In fact, zinc oxide coatings having thicknesses of 50 -150 nm are found [2] to remove heat 4-10 X faster than bare copper and aluminum surfaces, the porosity of zinc oxide thought to enhance heat transfer because of the increased area available.

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However, porosity in nanoscale coatings [1] is unlikely to provide the increased area to account for the observed [2] enhancement of heat transfer. Fundamentally, porosity at the nanoscale requires the atoms in the coatings to have the heat capacity to allow temperature changes, a condition consistent with classical physics. QM differs by requiring the heat capacity of atoms at the nanoscale to vanish, and therefore the heat into the coating cannot be conserved by the usual increase in temperature to allow the increased area available from porosity to enhance heat transfer. Porosity cannot explain [2] observations.

Instead, QED heat transfer [6] is proposed. Provided the coating has a higher RI than the substrate, the heat from the substrate under TIR is conserved by the QED induced creation of excitons inside the nanoscale coating that upon recombination enhance the heat transfer by emitting the heat as EM radiation to the surroundings. RI stands for refractive index. By QM, the dramatic heat transfer enhancement [2] for nanoscale zinc oxide coatings has nothing to do with porosity as the QED induced EM radiation bypasses the inefficient boiling process only to be absorbed directly in the coolant water.

QED cooling does not require pool-boiling or water coolant, and may dissipate heat directly to the ambient air surroundings, the latter of great interest in cooling electronics. Indeed, air cooling by coating conventional electronics circuit elements with nanoscale zinc oxide or other suitable materials is especially attractive [3, 4] and in nanoelectronics, perhaps the only possible way to cool submicron circuit elements. Similarly, gas turbine blades [5] may be cooled by QED. High-temperature nickel based superalloy blades with TBCs of at least 125 micron thick YSZ using highly sophisticated advanced cooling concepts are required to ensure high-performance gas turbines. TBC stands for thermal barrier coating and YSZ for yttria-stabilized zirconia. However, QED cooling based on QM requires the thickness of the TBC to be submicron while TBCs of YSZ are supramicron. Like nanoscale coating of electronics, whether submicron TBCs of YSZ are feasible for turbine blades is not yet proven.

2. PURPOSE

To present the QM theory of QED heat transfer and discuss the feasibility of applying nanoscale coatings to the surfaces of structures with application to electronics circuit elements and turbine blades.

3. THEORY

3.1 QM Restrictions Classically, the atoms in nanoscale coatings always have the heat capacity to increase in temperature upon the absorption of Joule or combustor heat irrespective of their thickness, i.e., there is no size effect in classical physics. QM differs in that the heat capacity of the atom depends on the thickness of the coating. A comparison of the thermal kT energy (or the heat capacity) of the atom by classical physics and QM by the Einstein-Hopf relation [7] for the harmonic oscillator is shown in Fig. 1.

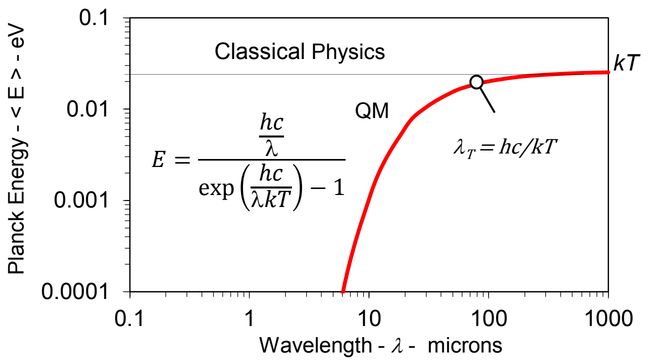

Fig. 1 Heat Capacity of the Atom at 300 K. E is Planck energy, h Planck's constant, c speed of light, k Boltzmann's constant, T temperature, and λ wavelength

QM allows the atom in supramicron coatings to have kT energy and increase in temperature for $\lambda > \lambda_T$. However, atoms in micron sized coatings confined to $\lambda < 6$ microns have $kT < 0.0001$ eV or little heat capacity, while at the nanoscale for $\lambda < 100$ nm virtually no heat capacity is available to conserve absorbed Joule or combustor heat by an increase in temperature.

3.2 TIR Confinement and QED Radiation TIR has a long history. In 1870, Tyndall showed light is trapped by TIR in the surface of a body if its RI is greater than that of the surroundings. Tyndall used water to show TIR confinement allowed light to be observed moving along the length of transparent curved tubes. TIR may confine any form of EM energy, although in nanoscale coatings of electronics and gas turbine blades the confined EM energy is the Joule heat and the heat from combustor gases, respectively.

TIR confinement requires the deposited heat to be concentrated in the coating surface that is a natural consequence of nanoscale coatings having high surface to volume ratios. Under TIR confinement, QED induces the absorbed heat to undergo spontaneous conversion to surface EM radiation, and specifically QED induced radiation. However, TIR confinement is not permanent, sustaining itself only during the heat absorption, i.e., absent absorption there is no TIR confinement and QED radiation is not produced.

QED relies on complex mathematics as described by Feynman [8] although the underlying physics is simple to understand, i.e., EM radiation of wavelength λ is created by supplying heat to a QM box with sides separated by $\lambda/2$. In this way, QED conserves electronic and combustor heat by frequency up-conversion to the TIR resonance described by the thickness d of the coating. The Planck energy E of the QED radiation,

$$E = h\upsilon, \quad \upsilon = \frac{c/n}{\lambda}, \quad \lambda = 2d \tag{1}$$

where, n is the RI of the coating.

3. ANALYSIS

In electronics, the wavelength of QED radiation emission from the conservation of Joule heat in nanoscale coatings of zinc oxide including the TBC of YSZ for turbine blades is shown in Fig. 2.

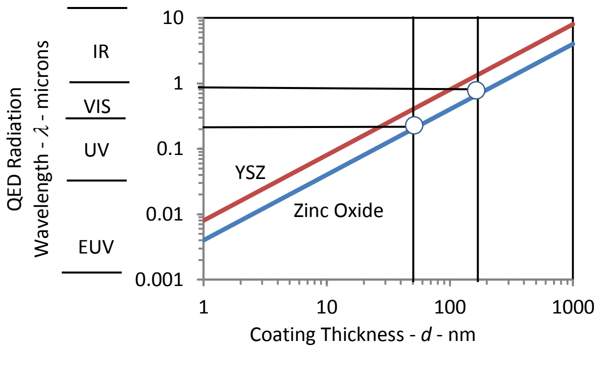

Fig. 2 QED Radiation Cooling Wavelength of QED Emission v. Coating Thickness

Generally, the QED emission from 50 – 150 nm coating thicknesses having RI from 2 to 5 occurs from the UV to the NIR. In water, all wavelengths except for the VIS are absorbed almost immediately while air is transparent for all wavelengths except for trace atmospheric gases. In air, absorption of QED radiation from coatings of electronics circuit elements and turbine blades therefore occurs at solid surfaces in the surroundings.

4. DISCUSSION

4.1 Thin Films Cooling by QED radiation in nanoscale coatings is not new, having been misinterpreted [9] for some time in thin films as reduced thermal conductivity because measured heat flow is lower than predicted by the Fourier equation. Because of this, the BTE was used [10] to explain the reduced conductivity in thin films by the scattering of phonons. BTE stands for the Boltzmann transport equation.

However, the BTE including the Fourier solutions are questionable because of the erroneous heat balances assumed for the films. The problem is thin films emit QED radiation beyond the UV to the surroundings [11] that is not included as a loss in the thin film heat balance, and therefore the thermal conductivity is concluded to be reduced from bulk. Alternatively, if the QED radiation loss is included in the balance, the conductivity remains at bulk. The exclusion of QED radiation from the heat balance is understandable as frequencies beyond the UV would normally not be observed during thin film experiments.

4.2 Comparison of Classical and QED Heat Transfer. Classical convective heat transfer applied to a coating on the surface of a body [12] dissipates heat Q supplied to the surroundings.

$$Q \;= HA(T - T_o) \tag{2}$$

where, T and T_o are the temperatures of the coating surface and the surroundings, H is the heat transfer coefficient, and A the surface area. QM precludes the temperature of the coating to increase, and therefore the temperatures of the coating and surroundings are the same, $T = T_o$.

$$H_{QED} = \frac{Q}{A(T - T_o)} \tag{3}$$

Since QED does not require a temperature difference to transfer the Q to the surroundings, the effective QED heat transfer coefficient H_{QRD} is therefore infinite, $H_{QED} >> H$. In comparison, natural convection heat transfer coefficients H in air are limited to 10 - 100 W/m^2-K. Classical heat transfer depends on temperature, but QED relying on QM does not. QED is therefore far more efficient than classical convective heat transfer.

4.3 Nanoelectronics QED radiation [3, 4] from nanoscale coatings is perhaps the only way of cooling nanoelectronics, as natural convection from traditional cooling fins are difficult to implement at the nanoscale. Provided the coating is submicron having a RI greater than the air and substrate surroundings, QM requires the heat capacity of the atom to vanish, and therefore Joule heat from the electronics cannot increase the temperature of the coating. Instead, the Joule heat is emitted as EM radiation from the coating to the surroundings, thereby cooling the nanoelectronics.

Nanoelectronics coated by ALD offer a simple means of implementing QED cooling. ALD stands for atomic layer deposition. Of importance is nanoelectronics operate in clean room environments, and therefore air contaminants are unlikely foul the coating and degrade the cooling provided by the QED coating. In contrast, QED cooling by nanoscale coatings of heat exchanger tubes or turbine blades is more likely to be reduced because of fouling by contaminants in the surroundings.

4.4 Gas Turbine Blades Gas turbine blades are coated [13] with TBC to insulate the blade from hot combustor gases. In contrast, QED coatings [5] do not insulate the blade from high temperature, but rather cool the blade by converting combustor heat to non-thermal EM radiation that is dissipated in the surroundings. Under the TIR confinement in nanoscale TBCs, the heat capacity of the atom vanishes, and therefore the TBC cannot conserve heat from the combustor gases by the usual increase in temperature. Instead, conservation proceeds by the QED induced frequency up-conversion of combustor heat to non-thermal EM radiation at the TIR confinement frequency of the TBC. QED cooling is passive avoiding the complexity [14] of active fin and internal cooling by transferring the combustor heat away from the blades.

Turbine blade QED coatings differ from those in nanoelectronics because it is difficult, if not impossible to keep the coatings clean from fouling by combustor gas residues. Moreover, the application of nanoscale QED coatings of YSZ on nickel superalloys by APS and ALD is not yet demonstrated. APS stands for atmospheric plasma spray. Conventional APS processes based on 10–100 microns particles are therefore unlikely to produce submicron TBCs. ALD of nanoscale YSZ coatings [15] on Si_3N_4 are encouraging, but research to determine whether ALD is capable of producing submicron TBCs on nickel based superalloy turbine blades remains to be proven. Research in APS or ALD technology is required to establish the feasibility of QED cooling of turbine blades by nanoscale YSZ coatings.

5. CONCLUSIONS

The significant enhancement in pool-boiling heat transfer found by coating bare aluminum and copper surfaces with 50-150 nm zinc oxide is not caused by the porosity of the coating. QM precludes the coating from increasing in temperature to take advantage of the greater heat transfer area provided by porosity. Instead, conservation proceeds by the creation of QED induced EM radiation under the TIR confinement of the nanoscale coating that upon emission is absorbed in the water coolant. However, fouling of the zinc oxide coating of pool-boiling tubing by contaminants may reduce the QED cooling efficiency.

QED radiation is created independent of pool-boiling provided the coating is submicron and has a higher RI than the substrate. Hence, water coolant is not required, the consequence of which is the emission of QED induced EM radiation in air is dissipated by solid surfaces in the surroundings, the latter of great interest because of its simplicity in cooling electronics. Indeed, air cooling by coating conventional electronics circuit elements with suitable nanoscale coatings is especially attractive and perhaps the only way to cool submicron circuit elements in nanoelectronics.

QED cooling is not new, but the beneficial effect has been misinterpreted as reduced thermal conductivity by the scattering of phonons in ballistic heat transfer based on the BTE of classical physics. By including QED radiation as a heat loss in the heat balance of electronics circuit elements or turbine blades as required by QM, the beneficial effects of QED cooling may be fully realized.

With regard to QED cooling of gas turbine blades, enhancement by nanoscale YSZ coatings similar to those in electronics are expected to take advantage of QM, but heat transfer efficiency may be reduced by fouling from combustor gas residues.

Research to determine whether nanoscale TBC thicknesses of YSZ on nickel based superalloys may be produced by APS or ALD is required to establish if the advantages of QED cooling offered by QM can be realized for turbine blades. The beneficial claims of QED cooling are sensitive to the coating being nanoscale as temperatures do indeed increase for supramicron coatings.

More experiments are required to support QED radiation as the fourth mode of heat transfer.

6. IMPACT ON SOCIETY

IHTC-15 asks how Science may better serve society. In this paper, QED radiation based on QM is proposed as the Fourth mode of heat transfer to conduction, radiation, and convection. But QED radiation is a theory, and as with any theory, whether societies benefit is usually measured by its impact on the reduction in economic cost to a commercial product. However, society may also benefit in non-economic ways, say by a better understanding of the world in which we live. QED in combination with QM explains [6] diverse areas of interest from biology to astronomy not possible by classical physics. QED in cosmology is selected here to show how man may benefit from his knowledge of the origin of the Universe.

Cosmologically, man has pondered the origin of the Universe. We know life has a beginning and an end, and it is only natural to think the Universe also has a beginning and an end. Yet, for thousands of years, the Universe was considered static and infinite - without a beginning and end. However, Einstein in 1916 introduced his field equations that required the Universe to not be static and infinite, but rather finite and either expanding or contracting. Since the notion of a static Universe is foreign to human experience that everything has a beginning and end, Einstein's field equations provided theoretical grounds to suggest the Universe is dynamic and finite. But lacking experimental verification, the dynamic and finite Universe lay dormant until 1929 when Hubble showed the light from distant galaxies was red-shifted. Interpreted by Doppler's effect, the redshift was taken as proof the Universe was expanding consistent with Einstein's field equations.

Since Hubble's discovery, Science based on Doppler's redshift considers the Universe as finite beginning and expanding since the Big Bang. Whether galaxies are moving away from or towards the Earth is determined by measuring the redshift of the light emitted from the atoms on the galaxies. Indeed, by interpreting the redshift by Doppler's effect, the velocity of the galaxy is thought measured.

Recently, Christof Wetterich, a theoretical physicist at the University of Heidelberg, has proposed [15] a radically different interpretation of cosmology in which the Universe is not expanding at all and instead, the mass of everything has been increasing. Because the speed of light is finite, when we look at distant galaxies we are looking backwards in time — seeing them as they would have been when they emitted the light that we observe. If all masses were once lower, the light of old galaxies would look redshifted in comparison to current frequencies, and the amount of redshift would be proportionate to their distances from Earth. Thus, the redshift would make galaxies seem to be receding when in fact they were not.

Mass induced redshift is plausible, but cannot be tested. Every mass on Earth is determined relative to a standard kilogram. If the mass of everything — including the standard — has been growing over time, there is no way to prove the mass of the Universe is indeed increasing. Other theories of redshift have been proposed to avoid an expanding Universe. After Hubble's discovery, Zwicky suggested the observed redshift is caused by "tired light" as photons lose energy through interactions with other particles, but like mass induced redshift cannot be tested. Nevertheless, cosmologists then and now generally consider the Universe as expanding only because Doppler's effect is the most convenient interpretation [16] of galaxies' redshift.

If, however, the redshifts could be shown to have a non-Doppler origin, the Universe need not be expanding. Redshift without an expanding Universe is of utmost importance because many of the outstanding problems in cosmology based on Doppler redshift measurements would be resolved.

In what follows, redshift of galaxy light is shown to occur upon absorption in submicron DPs by the mechanism of QED induced redshift as given above by QED heat transfer as the fourth mode of heat transfer. DP stands for cosmic dust particles. QED induced redshift may be understood by treating the absorbed photon as EM energy confined within the DP by TIR. TIR confinement is a consequence of QM that requires EM energy of any form to be confined to DP surfaces because of their high surface to volume ratios. Hence, the TIR confinement of the absorbed single galaxy photon is only momentary, and in effect sustains itself. Nevertheless, the EM energy of the absorbed photon creates a redshift photon depending on the properties of the DP. Blue shift does not occur because the energy required is greater than that of the absorbed galaxy photon. From Equation (1), the QED photon created is observed at wavelength λ_o,

$$\lambda_o = 2nD = 4na \tag{4}$$

where, D is the DP diameter, and $a = D/2$ is the DP radius. The redshift Z is,

$$Z = \frac{\lambda_o - \lambda}{\lambda} \tag{5}$$

where, λ is the wavelength of the galaxy light. Cosmic dust measurements [17] give the DP radius from a = 0.005 to 0.25 microns. Fig. 3 shows the redshift Z of Lyman-alpha (Lyα) lines for amorphous silicate having n = 1.5. At the upper bound DP radius of 0.25 microns, the Lyα lines are redshift to Z = 11.

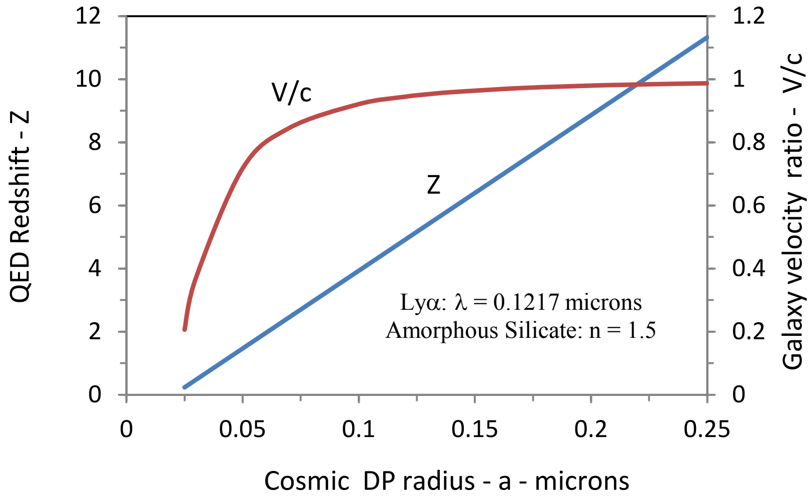

Fig. 3 Cosmic dust induced redshift of Lyα Line

Unlike redshift by mass and "tired light", QED induced redshift may be tested by laser interactions with nanoparticles. The QED induced redshift is caused solely by the absorption of the galaxy photon in cosmic dust and has nothing to do with an expanding Universe. Given that galaxy light is unequivocally absorbed by cosmic dust on its way to the Earth, the high galaxy velocities V inferred from the Doppler interpretation of Hubble redshift Z is therefore meaningless as the galaxy need not be receding at all. Relative to the velocity of light c, the Doppler velocity V of stars with redshift Z is,

$$\frac{V}{c} = \frac{(Z+1)^2 - 1}{(Z+1)^2 + 1} \tag{5}$$

Fig. 3 shows the galaxy velocity V inferred by the Doppler redshift of the LYα photon is a significant fraction of c even at low Z, e.g., for a = 0.025 microns, Z = 0.23 and V = 0.2 c. Therefore, any implied relation of dark energy [18] from Supernovae light to an expanding Universe is erroneous. What this means is the Universe may still be expanding and dark energy may exist, but Universe expansion cannot be proven from redshift measurements of Supernovae light because of cosmic dust.

But QED induced redshift has further consequences. Astronomers based on Doppler redshift measurements of stars orbiting black holes infer an incredible 50 billion solar masses at the center of the black hole are required to allow the star moving near the speed of light to stay in orbit. In contrast, QED induced redshift by cosmic dust in the line of sight of the optical measurement suggests the star velocity is highly exaggerated thereby placing in question the presence of 50 billion solar masses at the center of black holes. Indeed, cosmic dust holds in question the Hubble redshift as proof the Universe began in the Big Bang suggesting the notion once proposed by Einstein of a static Universe in dynamic equilibrium is a far more credible cosmology. Other consequences [6] of QED redshift in cosmic dust are:

Dark Energy not needed to explain a Universe that is not expanding
Period-luminosity relation qualified in Cepheid stars
Dark Matter not needed in Gravitational Lensing
Galaxy Rotation Problem resolved without Dark Matter
No need for MOND to explain Galaxy Rotation Problem
Tolman Surface Brightness reduction by (1 + Z)
Explain the Independence of Redshift in Sunyaev-Zeldovich Effect
Light Curve dilation in Supernovae Explosions

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