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QED Cooling of Structures by Nanoscale Coatings

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Abstract: Structures cool by conduction, radiation, and convection. However, by simply applying a nanoscale coating to the surface of a structure, cooling is dramatically enhanced. Classical physics that requires the same heat capacity of the atom for all coating thicknesses does not predict any enhancement for nanoscale coatings. QM differs by requiring the heat capacity of the atom in nanoscale coatings to vanish thereby precluding the conservation of heat by the usual increase in temperature. QM stands for quantum mechanics. Instead, structures cool as the heat into the coating under TIR is induced by QED to create non-thermal EM radiation thereby producing excitons (holon and electron pairs) that upon recombination enhance heat transfer by emitting the heat as EM radiation to the surroundings. TIR stands for total internal reflection, QED for quantum electrodynamics, and EM for electromagnetic. QED cooling is discussed in relation to the feasibility of applying nanoscale coatings to electronics circuit elements and gas turbine blades.

Keywords: nanostructures; coating; classical physics; quantum mechanics; quantum electrodynamics

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. However, QED following QM is far more efficient than classical heat transfer, but requires the surfaces of the structures to be provided with nanoscale coatings.

Pool-boiling and Nanoscale Coatings

Recently, a review [1] of heat transfer between a solid wall 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 because of nanometer dimensions. However, nanoscale coatings of zinc oxide having thicknesses of 50 -150 nm are contrarily found [2] to remove heat 4-10 X faster than bare copper and aluminum surfaces, the porosity of zinc oxide thought to remove heat faster because of the increased area available for heat transfer.

But to take advantage of the increased area provided by porosity, the atoms in the coatings are required to have heat capacity to allow temperature changes, a condition consistent with classical physics. However, 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. Provided the coating has a higher RI than the substrate, the heat under TIR is instead 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 and is absorbed directly in the coolant water.

QED Cooling of Electronics and Turbine Blades

QED cooling does not require pool-boiling or water coolant, and may dissipate heat 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] and perhaps the only possible way to cool submicron circuit elements in nanoelectronics.

Electronics cooling by QED suggests gas turbine blades may be similarly cooled. High-temperature nickel based superalloy blades with TBCs of at least 125 micron thick YSZ using highly sophisticated advanced cooling concepts are thought [4] required to ensure high-performance gas turbines. TBC stands for thermal barrier coating and YSZ for yttria-stabilized zirconia.

Currently, the TBCs function to insulate the blade from high temperature combustor gases. QED cooling based on QM is consistent with turbine blades in that YSZ has a RI greater than that of nickel based super alloy blades. However, QM also requires the thickness of the TBC to be submicron while TBCs of YSZ are supramicron.

Like coatings on electronics, whether submicron TBCs of YSZ can be applied to turbine blades is not yet proven. APS or ALD technology is required to establish the economic feasibility of QED cooling of structures by coating surfaces. APS stands for atmospheric plasma spraying and ALD for atomic layer deposition.

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.

Materials and method

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 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 [5] for the harmonic oscillator is shown in Fig. 1.

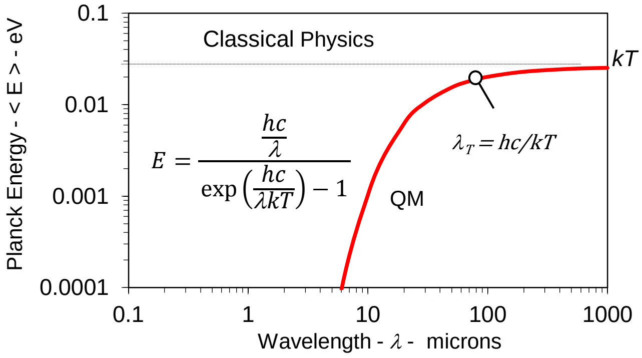

Fig. 1 Heat Capacity of the Atom at 300 K
is Planck energy, h Planck's constant, c speed of light, k Boltzmann's constant, T temperature, and λ wavelength

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.

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 transmitted through curved tubes. TIR may confine any form of EM energy, although in electronics and gas turbine blade coatings 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, 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 [6] although the underlying physics is easy 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.

Results

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.

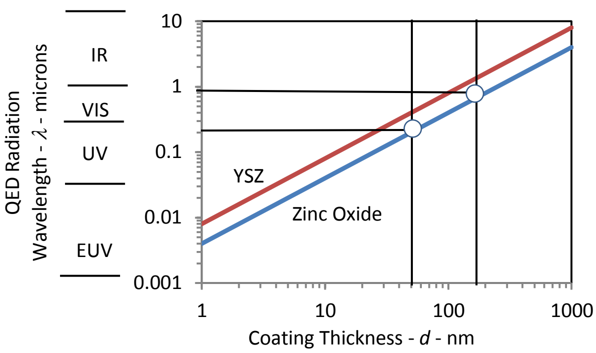

Fig. 2 QED Radiation Cooling
Wavelength of QED Emission v. Coating Thickness

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.

Discussion

Thin Films

Cooling by QED radiation in nanoscale coatings is not new, having been misinterpreted [7] for some time in thin films as reduced thermal conductivity because measured heat flow is lower than predicted by the Fourier equation. In this regard, the BTE simulating ballistic heat transfer in thin films by the scattering of phonons is thought [8] to explain the reduced conductivity. BTE stands for the Boltzmann transport equation.

However, the BTE including the prior Fourier solutions are questionable because of the heat balances assumed for the films. The problem is thin films emit QED radiation beyond the UV to the surroundings [9] that is not included as a loss in the 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 expected during thin film experiments.

Comparison of Classical and QED Heat Transfer

QED heat transfer converts heat Q_{QED} in the coating to EM radiation that is dissipated in the surroundings.

$$Q_{QED} \quad = HA(T - T_{surr}) \tag{2}$$

where, T and T_{surr} are the temperatures of the coating and the surroundings, H is an effective heat transfer coefficient, and A the area. QM precludes the temperature of the coating to increase, and therefore the temperatures of the coating and surroundings are the same, $T = T_{surr}$. Since QED does not require a temperature difference to transfer the Q_{QED} to the surroundings, the effective QED heat transfer coefficient H is therefore infinite.

In comparison to QED, natural convection heat transfer coefficients H in air vary between 10 and 100 W/m^2-K. Classical heat transfer depends on temperature, but QED relying on QM does not. By QM, QED is therefore far more efficient than classical heat transfer.

Conclusions

The significant enhancement in pool-boiling heat transfer found by coating aluminum and copper 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.

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 radiation is simply dissipated in the ambient air 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 based on the BTE or the reduced heat flow from that predicted by the Fourier equation. By including QED radiation as a loss in the heat balance of electronics circuit elements or turbine blades, the beneficial effects of QED cooling may be fully realized.

With regard to QED cooling of gas turbine blades, enhancements similar to those in electronics are expected to take advantage of QM, but may be difficult to implement in practice. Consistent with QM, TBCs of YSZ have RIs greater than nickel based superalloy blades, but the thicknesses varying from 200 to 5000 microns are far larger than the submicron thicknesses required by QM.

Research to determine whether submicron TBC thicknesses of YSZ on nickel based superalloys may be manufactured 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 submicron as temperatures do increase for supramicron coatings.

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