MODELLING AND SIMULATION OF INTERACTION OF MAGNETOBREMSSTRAHLUNG RADIATION AND NIHONIUM NANOPARTICLES USING BENDING MAGNETS, UNDULATORS AND/OR WIGGLERS IN STORAGE RINGS FOR HUMAN CANCER CELLS, TISSUES AND TUMORS TREATMENT

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ABSTRACT: *In the current study, thermoplasmonic characteristics of Nihonium nanoparticles with spherical, core-shell, and rod shapes are investigated. In order to investigate these characteristics, the interaction of synchrotron radiation emission as a function of the beam energy. Firstly, absorption and extinction cross-sections were calculated. Then, increases in temperature due to synchrotron radiation emission as a function of the beam energy absorption were calculated in Nihonium nanoparticles by solving the heat equation. The obtained results show that Nihonium nanorods are a more appropriate option for using in onto thermal human cancer cells, tissues, and tumors treatment method.*

Keywords: Magnetobremsstrahlung Radiation, Bending Magnets, Undulators, Wigglers, Storage Rings, Nihonium Nanoparticles, Scanning Electron Microscope (SEM), 3D Finite Element Method (FEM), Heat Transfer Equation, Optothermal, Heat Distribution, Thermoplasmonic, Nihonium Nanorods, Human Cancer Cells, Tissues and Tumors Treatment, Simulation, Synchrotron Radiation, Emission, Function, Beam Energy

1. INTRODUCTION

In the past ten years, synchrotron radiation generated by circulating electron or positron beams has been widely used as a powerful X-ray photon source in several fields [1–3]. Recently high energy electron or positron synchrotron storage rings [4–6] to provide more brilliant and higher flux photons have been proposed and are being constructed. The bending magnet enables electrons to circulate in the closed-loop of the storage ring and most of the photons generated should be absorbed before striking the wall of the vacuum chamber of the storage ring and the rest of those are extracted for experimental use. Photon absorbers [7, 8] have been installed in an ultra-high vacuum storage ring to absorb unwanted photons. Since synchrotron radiation generated by a high energy ring is very powerful, concentrated and penetrating, the absorber is subjected to the extremely high internal heat (comparable to that of an electron beam welding machine). Depending on the materials used, this energy generation may be restricted to the region near the surface or distributed throughout the absorber decaying exponentially in the direction of the penetration. The cooling of the absorber is important not only to prevent the melting of the material but also to ensure an ultra-high vacuum (~/0–9torr) in a storage ring. Note that photon energy deposition in the metal causes the desorption of gases, which would result in significant increases in the pressure [9, 10]. Inclined photon absorbers have been considered [5, 7, 11] in order to reduce the high wall heat flux; the inclination of the plate to the photon direction increases the photo projection area, and correspondingly, decreases the heat flux. Since copper (Cu), which has generally been used as an absorber material absorbs most of the photons very near the surface, the temperature of the surface becomes very high despite the high thermal conductivity. On the other hand, beryllium (Be), which has been widely used to isolate a storage ring from the experimental line due to its relative transparency to X–rays, diffuses the intense radiation throughout the plate, even though it has a much lower thermal conductivity than copper. To combine the merits of Be and Cu, a Be–Cu composite cylinder has been developed [12] and successfully used. The heat transfers for single or multilayers caused by the absorption of photons has been studied with applications to laser processing and composite materials [13–16]. In the present work, inclined single and double layer absorbers are analyzed and analytical and numerical solutions are obtained. The effects of the variable absorption coefficient of the metal, which is dependent on the photon spectrum and variable thermal conductivity are examined for different materials. In addition, the effects of different thickness ratios and different inclination angles are also studied for the double layer absorber. The present approach can also be applied to other fields; e.g. laser processing and heat transfer in composite materials.

In recent decade, metallic nanoparticles have been widely interested due to their interesting optical characteristics [1–10]. Synchrotron radiation emission as a function of the beam energy absorption and induced produced heat in nanoparticles has been considered as a side effect in plasmonic applications for a long time [11–15]. Recently, scientists find that thermoplastic characteristics can be used for various optothermal applications in cancer, nanoflows, and photonic [16–22]. In optothermal human cancer cells, tissues and tumors treatment, the descendent laser light stimulate resonance of surface Plasmon of metallic nanoparticles and as a result of this process, the absorbed energy of descendent light converse to heat in nanoparticles [23–25]. The produced heat devastates tumor tissue adjacent to nanoparticles without any hurt to sound tissues [26, 27]. Regarding the simplicity of ligands' connection to Nihonium nanoparticles for targeting cancer cells, these nanoparticles are more appropriate to use in optothermal human cancer cells, tissues, and tumors treatment [28–74]. In the current paper, thermoplasmonic characteristics of spherical, core-shell, and rod Nihonium nanoparticles are investigated (Figure 1).

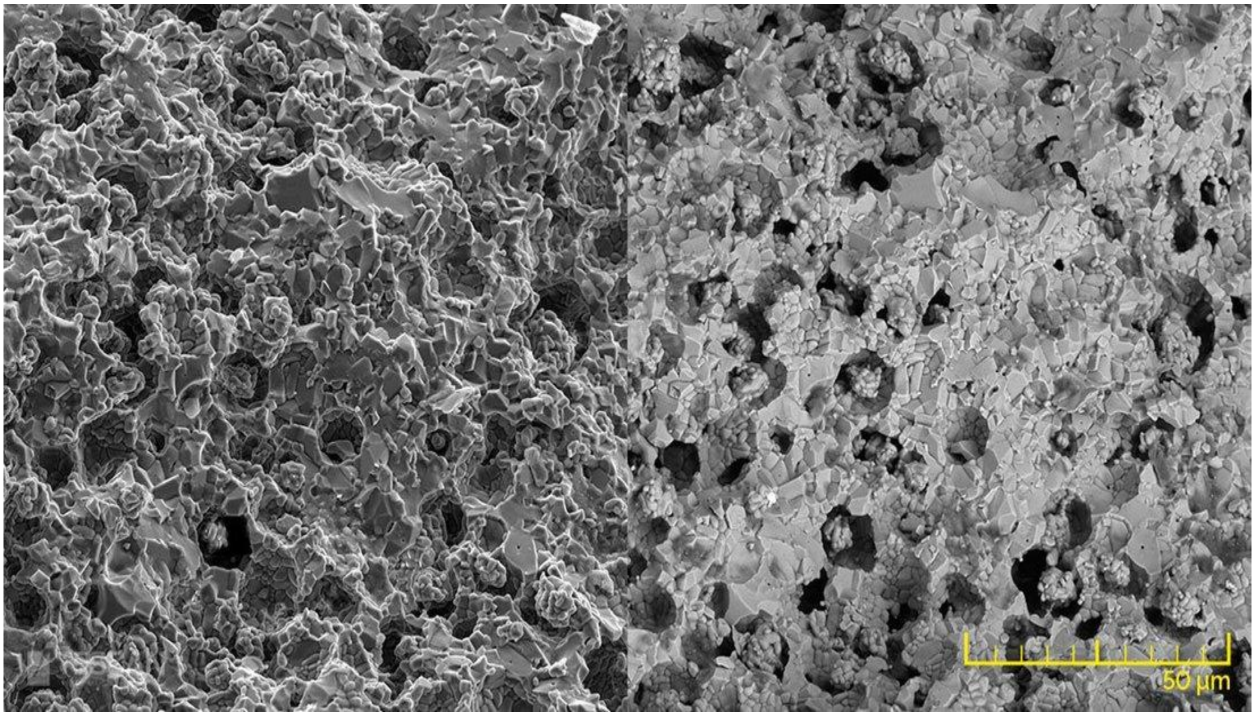

Figure 1: Scanning Electron Microscope (SEM) image of Nihonium nanoparticles with 50000x zoom.

2. MATERIALS AND ANALYSIS METHODS

The heat transfer phenomena for single and double layer inclined absorbers which absorb synchrotron radiation has been studied using analytical and numerical methods. Photon penetration through the metal layers has been included and the effects of the spectral variation of the absorption coefficients and variable thermal conductivities have been examined. Different thickness ratios and inclination angles have been studied for double layer absorbers and it has been shown that double-layer inclined absorbers significantly reduce the peak temperatures.

When Nihonium nanoparticles are subjected to descendent light, a part of light scattered (emission process), and the other part absorbed (non–emission process). The amount of energy dissipation in non–emission process mainly depends on the material and volume of nanoparticles and it can be identified by the absorption cross-section. On the other hand, the emission process in which its characteristics depend on volume, shape, and surface characteristics of nanoparticles explains by scattering cross-section. The Sum of absorption and scattering processes which lead to light dissipation is called extinction cross-section [75–123].

Nihonium nanoparticles absorb the energy of descendent light and generate some heat in the particle. The generated heat transferred to the surrounding environment and leads to an increase in temperature of adjacent points to nanoparticles. Heat variations can be obtained by the heat transfer equation [124–202].

3. RESULTS AND DISCUSSION

To calculate the generated heat in Nihonium nanoparticles, COMSOL software which works by Finite Element Method (FEM) was used. All simulations were made in 3D. Firstly, absorption and scattering cross-section areas were calculated by the optical module of the software. Then, using the heat module, temperature variations of nanoparticles and its surrounding environment were calculated by data from the optical module [203–283]. In all cases, Nihonium nanoparticles are presented in a water environment with a dispersion coefficient of 1.84 and are subjected to flat wave emission with linear polarization. The intensity of descendent light is 1 $mW/\mu m^2$. The dielectric constant of Nihonium is dependent on particle size [284–393].

Firstly, calculations were made for Nihonium nanospheres with a radius of 5, 10, 15, 20, 25, 30, 35, 40, 45, and 50 nanometers. The results show that by an increase in nanoparticles size, extinction cross-section area increases and maximum wavelength slightly shifts toward longer wavelengths. The maximum increase in temperature of nanospheres in surface Plasmon frequency is shown in Figure (2).

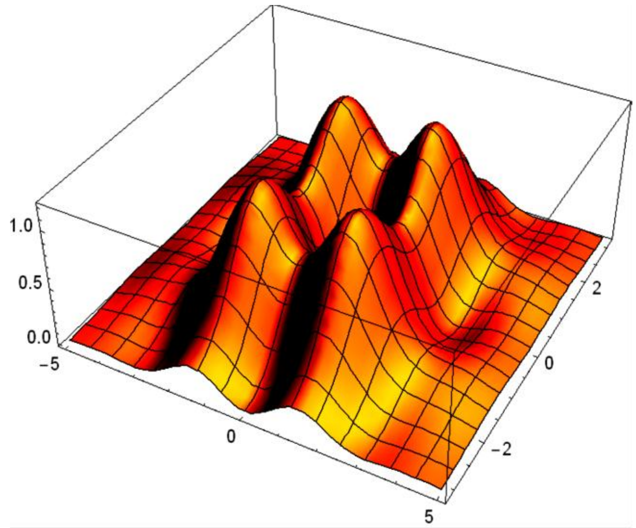

Figure 2: Maximum increase in temperature for Nihonium nanospheres.

The heat transfers through single and double layer inclined absorbers which absorb synchrotron radiation emitted by circulating charged particles was studied using analytical and numerical methods. The effects of variable absorption coefficient and thermal conductivity were examined. The cases of different thickness ratios and inclination angles were studied for double layer absorbers. The following conclusions have been made (Figure 3).

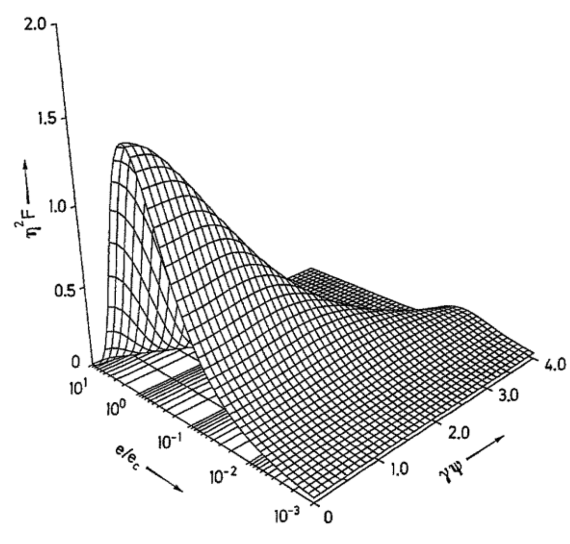

Figure 3: Spectral and angular distribution of dimensionless synchrotron radiation power per normalized photon energy.

According to the graph, it can be seen that the generated heat is increased by an increase in nanoparticles size. For 100 (nm) nanoparticles (sphere with 50 (nm) radius), the maximum increase in temperature is 83 (K). When nanoparticles size reaches 150 (nm), an increase in temperature is increased in spite of the increase in the extinction coefficient. In order to find the reason of this fact, the ratio of absorption to extinction for various nanospheres in Plasmon frequency is shown in Figure (4).

Figure (4) shows that increasing the size of nanospheres leads to a decrease in the ratio of light absorption to the total energy of descendent light so that for 150 (nm) nanosphere, scattering is larger than absorption. It seems that although an increase in nanoparticle size leads to more dissipation of descendent light, dissipation is in the form of scattering and hence, it cannot be effective on heat generation.

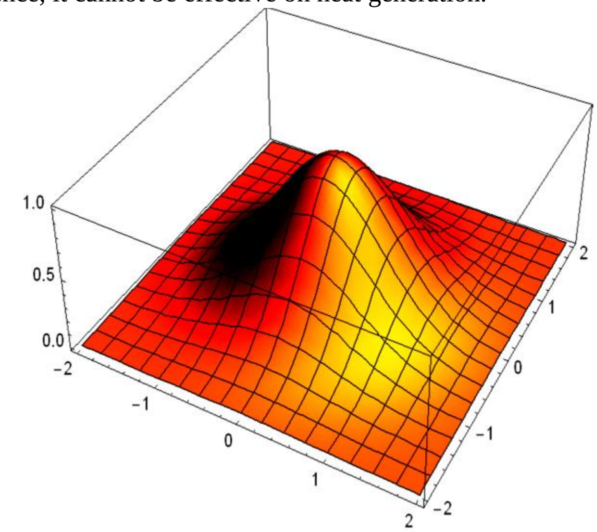

Figure 4: Variations of absorption to extinction ratio and scattering to extinction ratio for Nihonium nanospheres with various radiuses.

Heat distribution (Figure 5) shows that temperature is uniformly distributed throughout the nanoparticles which are due to the high thermal conductivity of Nihonium.

In this section, the core-shell structure of Nihonium and silica is chosen. The core of a nanosphere with 45 (nm) radius and silica layer thickness of 5, 10, 15, 20, 25, 30, 35, 40, 45, and 50 nanometers are considered. The results show that an increase in silica thickness leads to an increase in the extinction coefficient and a shift in the Plasmon wavelength of nanoparticles, to some extent.

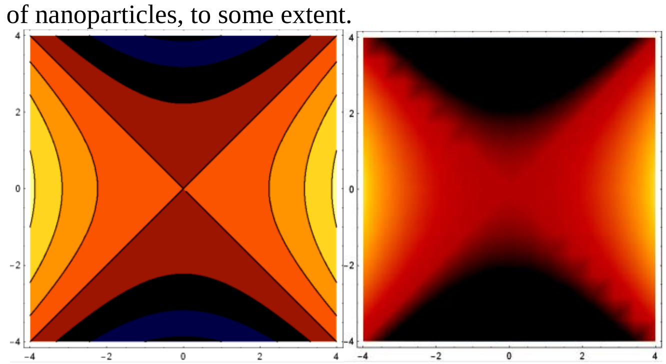

Figure 5: Maximum increase in temperature for spherical nanoparticles with a radius of 45 (nm) at Plasmon wavelength of 685 (nm).

According to Figure (6), silica shell causes a considerable increase in temperature of Nihonium nanoparticles but by more increase in silica thickness, its effects are decreased. Heat distribution (Figure 7) shows that temperature is uniformly distributed throughout the metallic core as well as silica shell. However, silica temperature is considerably lower than the core temperature due to its lower thermal conductivity. In fact, the silica layer prohibits heat transfer from metal to the surrounding aqueous environment due to low thermal conductivity, and hence, the temperature of nanoparticles has more increase in temperature. Increasing the thickness of the silica shell leads to an increase in its thermal conductivity and hence, leads to attenuate in an increase in nanoparticles temperature.

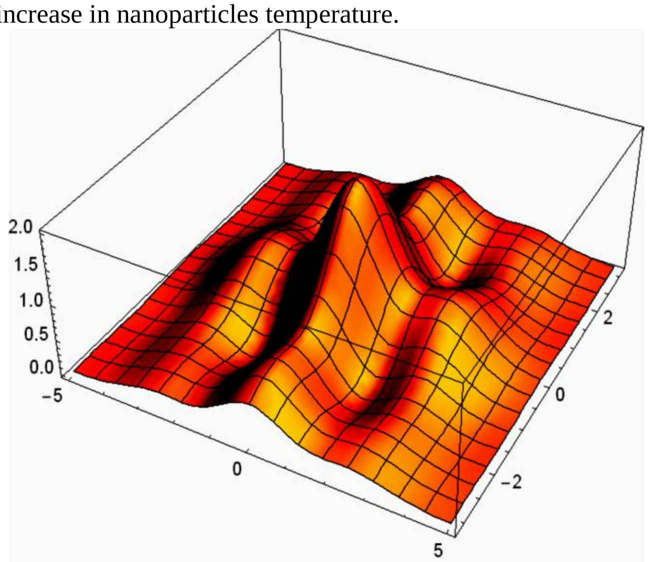

Figure 6: Maximum increase in temperature for core-shell Nihonium nanospheres with various thicknesses of the silica shell.

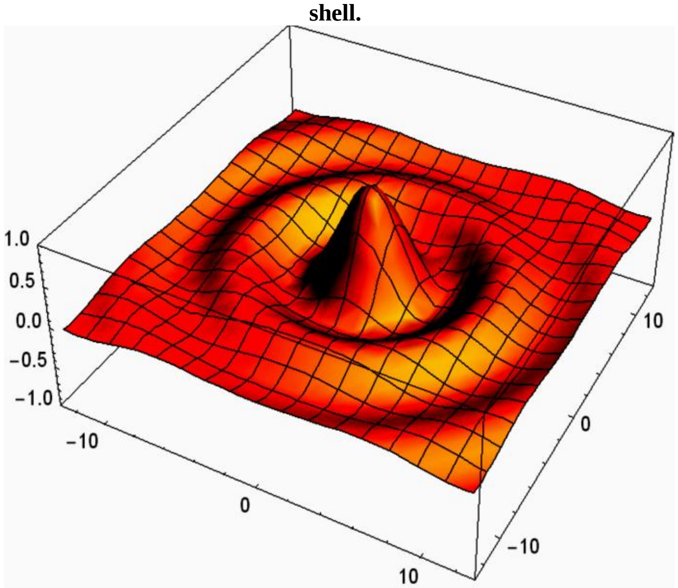

Figure 7: Maximum increase in temperature for core-shell nanoparticles with a radius of 45 (nm) and silica thickness of 10 (nm) at Plasmon wavelength of 701 (nm).

Figure (8) is drawn. This graph shows that the variation of the nanorod dimension ratio leads to a considerable shift in Plasmon wavelength. This fact allows regulating the Plasmon frequency to place in near IR zone. Light absorption by body tissues is lower in this zone of the spectrum and hence, nanorods are more appropriate for optothermal human cancer cells, tissues, and tumors treatment methods.

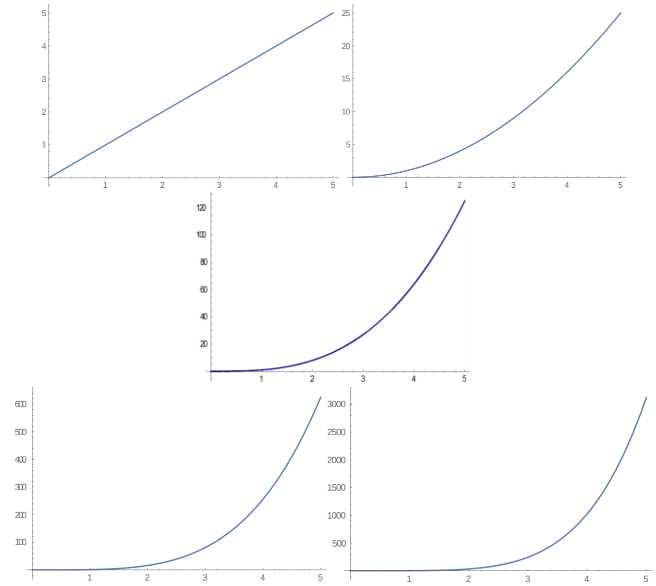

Figure 8: Extinction cross-section area for Nihonium nanorods with an effective radius of 45 (nm) and various dimension ratios. Variations of temperature in Nihonium nanorods with two effective radius and various dimension ratios are shown in Figure (9). By an increase in length (a) to the radius (b) of the nanorod, the temperature is increased.

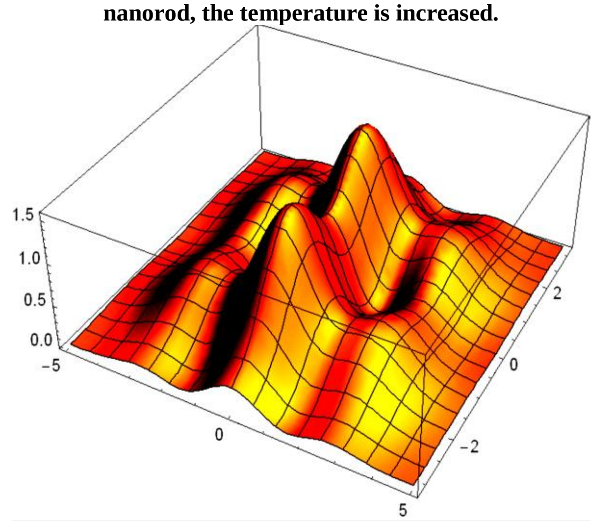

Figure 9: Maximum increase in temperature for nanorods with an effective radius of 20 and 45 (nm) and various dimension ratios.

4. CONCLUSION AND SUMMARY

For large atomic number (Z) materials, such as Nihonium, Z=113, most of the photons are deposited very near the surface, and surface deposition may be a reasonable assumption for the determination of the heat flow. However, for smaller Z materials, e.g. Copper, Z = 29, photons penetrate with relative ease through a significant depth of the plate, and the assumption of surface deposition is no longer valid. In the present work, the general case of penetrating photon beam heating is considered for both single and double layer inclined plates.

The calculations showed that in Nihonium nanoparticles, light absorption in Plasmon frequency causes to increase in temperature of the surrounding environment of nanoparticles.

In addition, it showed that adding a thin silica layer around the Nihonium nanospheres increases their temperatures. Calculations of nanorods showed that due to the ability for shifting surface Plasmon frequency toward longer wavelength as well as more increase in temperature, this nanostructure is more appropriate for medical applications such as optothermal human cancer cells, tissues, and tumors treatments.

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