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P1_2 Melting Mirrors

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Abstract

High powered lasers have been portrayed as being able to cut through almost anything, but a simple mirror seems to easily reflect them. The purpose of a mirror is to reflect optical light but there is a limit to the energy it can do so before it begins to deform and melt. Thorough research into this showed that if we consider a mirror with an optical coating of silver and a 500 nm laser was applied to it, it would take 12.11 J to destroy the illuminated area, if thermal conductivity and scattering were not considered.

Introduction

In many popular action movies and video games, high powered lasers have been visualised as weapons of unstoppable force, along with other deadly super weapons. They appear to cut through almost anything in their path, and yet such a weapon seems to be defeated by means of a reflective material i.e. a mirror. For such a high powered laser to be so easily reflected raises the question; is this possible for a mirror to reflect such a high powered laser beam without being destroyed?

Discussion

In reality, mirrors are not 100% reflective. A material's reflectivity varies depending on the optical coating, thickness of material, intensity and wavelength of the beam, as well as the duration the laser beam being active. Angle of incidence may also be a contributing factor. We will assume that the energy delivered to the mirror is instantaneous.

Consider a mirror with an optical coating of silver 0.5mm thick on glass 3mm thick of densities $\rho_s = 10490$ kg m^{-3} and $\rho_g = 2.4$x10^3 kg m^{-3} [5] respectively. The melting point of silver is 1235 $^{\circ}$C and glass is between 1600°C to 1650°C [5]. Consider a laser of wavelength 500nm, the reflectivity of silver is around 90% [4] at this wavelength and assume a cylindrical beam of radius is 0.5mm which has no divergence. Specific heat of glass and silver are $c_g = 0.84$ J g^{-1} K^{-1} and $c_s = 0.233$ J g^{-1} K^{-1} respectively. [5]

Equations

By first considering the specific heat equation

$$Q = mc\Delta T, \qquad (1)$$

where Q is the heat energy, m is the mass of the material, c is the specific heat capacity, and ΔT is the change in temperature of the material. The beam must first penetrate through the glass before reaching the silver. In order to work out the mass of glass and silver heated, use

$$m = \rho V, \qquad (2)$$

where m is mass, ρ is the density and V is the volume ($\pi r^2 h$) where r is the radius and h is the height. Substituting values into equation 2 gives a mass of glass to be 5.655x10^{-6} kg and silver to be 4.12x10^{-6} kg. The change in temperature ΔT is defined as the difference between room temperature and melting temperature for each material; for glass it is $\Delta T_g = 1580$°C and for silver it is $\Delta T_s = 1215$°C (assuming standard temperature and pressure, STP).

The latent heat on the silver changing phase must be considered as the silver under

goes fusion. Latent heat for fusion for silver is 111KJ/kg [6]. Using the equation,

$$Q = mL, \tag{3}$$

where m is the mass, L is the specific latent heat of fusion and Q is the energy released.

Emissivity of silver at 38°C is 0.01 and 0.02 at 260°C. The emissivity is low and can be ignored over the very short time scale of the laser heating the mirror.

Result

Using equation 1, the energy required to melt the mirror can be calculated. For this case, glass is extremely transparent against optical wavelengths so absorption is negligible. Silver has a reflectivity of 90% at 500 nm [4] so only 10% of the light will be absorbed by the silver. Using equation 1 we get the result of 11.65 J, equation 3 produces a result of 0.457J. Therefore a total of 12.11J, is the energy required from the laser beam; this is assuming all energy is absorbed by the material and converted into internal energy and the heat is not conducted away.

Analysis

This result is an estimate of the minimal required energy of the laser beam. Silver has a non-linear relation between wavelength and reflectivity due to its crystal structure; at around 300 nm silver becomes almost completely absorbent [4]. Any wavelengths below that and the silver become reflective again, albeit at a lower reflectance.

The high temperature needed to melt the silver causes a larger thermal gradient across the mirror from the illuminated area to the edge of the mirror. Silver has a high thermal conductivity, allowing it to transport heat rapidly which is beneficial considering the short burst of energy we are transmitting. The 12.11J of energy is not an extreme amount of energy for most modern lasers. A 20 W laboratory laser would melt the mirror in

approximately 0.61 seconds. However mirrors can be reinforced or other materials can be used with a higher melting point to increase the durability of the mirror.

Conclusion

To summarise, if conductivity and scattering is ignored, lasers with a wavelength of 500 nm and lower will melt a mirror with silver as its optical coating. Different materials will have different melting points and reflectivity; however a powerful enough laser beam will deform the material and thus, melt the mirror. If further investigation were to be performed, we would recommend taking into account thermal conductivity.

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