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P4 5 No Mr Bond: I expect you to die!

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Abstract

We investigate the laser used in the 1964 film *Goldfinger*, during the scene of James Bond tied to the table, watching a laser cut through gold. We find that to completely vaporise the gold in this fashion, it would correspond to a laser power of approximately 27.40 kW, which is possible by the lasers of the time. We also consider that the actual requirement to vaporise gold in this way is significantly affected by thermal conduction and radiative losses, finding this increases the power requirement to 35.16 kW.

Introduction

In the 1964 film *Goldfinger*, James Bond is put into a tricky situation of being tied down to a table, with a laser slowly approaching him. Goldfinger places a sheet of gold in front of Bond and has the laser cut through it to demonstrate its power. In this paper we determine how realistic the power of the laser on display is, by considering its power including losses due to thermal conduction and thermal radiation.

Laser Power Without Losses

Goldfinger states that the laser can 'cut through some metals', we interpret this as the laser heating the gold sheet to be vaporised. If the gold sheet is initially at room temperature $T_0 = 293$ K, then the energy, Q_1 required to bring it to its melting point $T_{melt} = 1337.15$ K is given by [1]

$$Q_1 = mc(T_{melt} - T_0) \quad (1)$$

Where m is the mass of the gold and $c = 129$ Jkg^{-1}K^{-1}, the specific heat capacity of gold [2]. The energy to melt the gold, Q_2 is given by

$$Q_2 = mL_f \quad (2)$$

Where $L_f = 63000$ Jkg^{-1}, which is the latent heat of fusion for gold [3]. Then the energy Q_3 to bring the gold to boiling point [4] $T_{boil} = 3129.15$ K

$$Q_3 = mc(T_{boil} - T_{melt}) \quad (3)$$

Then finally the energy to boil the gold, Q_4 is given by

$$Q_4 = mL_v \quad (4)$$

Where $L_v = 1.7 \times 10^6$ Jkg^{-1}, the latent heat of vaporisation for gold [3]. Hence the energy for the entire process, Q is given by

$$Q = Q_1 + Q_2 + Q_3 + Q_4 \quad (5)$$

The mass of the gold that is cut through can be estimated by,

$$m = \rho A d \quad (6)$$

Where $\rho = 19320$ kgm^{-3}, the density of gold [5]. A is the area cut through and d is the depth of the cut. From reviewing the scene, after about 45 seconds, the cut appears to be approximately 30 cm long and about 1 cm wide and deep. Hence the mass of the gold cut through is $m \approx 0.58$ kg.

Therefore by substituting this value into equations (1), (2), (3) and (4), we can determine all of the required temperatures as $Q_1 = 7.80 \times 10^4$ J, $Q_2 = 3.65 \times 10^4$ J, $Q_3 = 1.34 \times 10^5$ J and $Q_4 = 9.85 \times 10^5$ J.

As stated earlier the laser is active for about $t = 45$ seconds hence the power of the laser is given by

$$P = \frac{Q}{t} \tag{7}$$

Hence we have overall the power of the laser is $P = 27.4$ kW. In comparison the most powerful lasers in the 1960s were ruby Q-switched lasers which could achieve power of about 1 MW [6].

Laser Power including Losses

It is important to note that really the value should be higher than this, as gold is a very reflective material, so a lot of the power from the laser is lost by simple contact with the surface.

Factoring in thermal conductivity losses, as the energy supplied to the gold is conducted away into the table underneath it. The heat transfer rate is given by Fourier's Law of Heat Conduction [7].

$$\dot{Q}_{conduct} = kA\frac{\Delta T}{x} \tag{8}$$

Where k is the thermal conductivity of gold (318 $\mathrm{Wm^{-1}K^{-1}}$) [8], A is the area of the heated region (Laser spot size, assuming a diameter of 1 cm, equal to 78.54×10^{-6} $\mathrm{m^2}$), ΔT is the temperature difference of the gradient (in this case the contrast between the boiling temperature of gold and the room temperature table) and, x is the thickness of the temperature gradient (1 cm at surface of the gold).

For the surface case, with x as 1 cm we find that the conductive losses are equal to 7083 W which will be added into the power of the process. As for the minimum thickness it could vaporise the gold too before conductive losses dominate power output, we rearrange the equation above for thickness assuming the laser has approximately the power of the most powerful laser of the time period 1 MW and determine a minimum thickness of vaporisation of 1.618×10^{-6} m (this assumes the table is an 'infinite sink' of thermal energy and never reaches equilibrium with the gold).

As for radiative losses through thermal radiation, the Stefan-Boltzmann equation gives a good approximation [9]

$$Q_{rad} = \epsilon\sigma AT^4 \tag{9}$$

Where ϵ is the emissivity of gold (0.035 for pure, polished gold [10]), σ is the Stefan-Boltzmann constant, A is the area of the heated section and, T is the temperature of the body. The energy losses to thermal radiation come out to ≈ 15 J.

Factoring in these two sources of losses, the power requirement of the laser now becomes 35.16 kW so an increase in power requirement of (7.76 kW) and still within the limit of the periods technology limits.

Discussion/Conclusion

The minimum laser power suggests that the scene is not beyond the technology of the time. The high powered pulsed lasers in the 1960s could reach powers on the order of megawatts [6], well above the requirement estimated. As gold is a good conductor of heat, we find this to be the dominant effect for where the losses in the laser power go to. Despite golds high reflectance, the radiative losses are greatly reduced by the small area that the laser is heating.

However it should be noted that the practicality of operating a laser like this at the time would have involved larger equipment, cooling and stability than is portrayed in the scene. So while in principle the scene is not unrealistic, there are many other factors in the laser operation that are omitted.

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