Mathematical Model of Effect of Number of Pulses of Pulsed Laser on Formation Process of Plasma

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Abstract

The effect of number of pulses of pulsed laser on materials is studied analytically, different pulses has been used with the same delay time. The depth of possible damage to the surface of copper and titanium as well as depth of the crater to both materials were considered in this study. The study revealed that linear model is only possible when estimating depth of possible damage for copper material, this means that the depth of possible damage increases with the increment of number of laser pulses .As for titanium material, it is found the relationship is nonlinear.

The depth of possible damage of titanium and copper is not the same, and copper seems to be more predictable than titanium.

key words: Pulsed laser, delay time, linear models, copper.

Introduction

Since the discovery of the laser, researchers began irradiating almost every conceivable target material and phase for novel basic physical and chemical study in addition to new applications. Pulsed-laser deposition (PLD) technique has been successfully applied to a wide range of materials. In the laser ablation process, high-power laser pulses are focused onto the surface of a bulk target typically at an angle of incidence of 45° with respect to its perpendicular direction. The ablation of the target produces a visible plasma (commonly known as "plume") that expands from the target[1].

The production of high temperature plasmas with small scale, short pulse, high intensity lasers has been actively pursued during the last three decades. Of particular interest in these studies is the measurement of the energy absorption efficiency of high density plasmas created by intense irradiation of a solid target, and many groups have published work measuring solid target plasma absorption efficiency over a wide range of incident intensities and laser wavelengths on planar[2-6] and micro structured targets[7]. These studies have shown that the plasma typically absorbs a large fraction of the laser energy, between 10% and 80% of the incident energy, depending upon intensity and laser wavelength. Such experiments have shown that a large amount of energy can be deposited per unit area and that high temperatures about 100 eV are achievable[2,8]. However, rapid heat conduction into the cold, solid substrate beneath the plasma will typically clamp the plasma temperature to a value of 1000 eV[8-10]. Furthermore, most of the deposited energy is contained within the plasma electrons, which cool too rapidly by conduction and hydrodynamic expansion to transfer much of this laser energy to the cold ions.

Data collection

A rough idea of the size of a crater can be obtained by considering the following: Pressure is the energy per unit volume, P = dE/dV ≈ E/V, where E is the energy of the pulse delivered to the material and V is the volume of the plasma (or the gas that condenses from the plasma). If the pressure is above the strength of the material K, the material give way as it is pushed aside by the plasma. We can therefore find the approximate volume of the excavated crater by setting E/V = K. Assuming the crater is a cylinder with a depth equals to its radius, the radius of the crater will be approximately Rc = (E/(π K))1/3. The software that is designed for estimating beam parameters of pulse energy (Materials response to peak intensity.htm) is used here for simulation purposes of this paper. This program is an interactive use interface which can be used directly from the internet (how to build a laser death ray.htm).The user interface of program contained two main categories ;the first is that deals with the type of material and some of the laser parameters of interest, the second category contained some important parameters of material. Both categories lead to the same output. The program has been run frequently in this research according to the need due to varying number of pulses as well as delay time.

Results

For both copper and titanium material, pulsed laser (x) will be considered as an independent variable while the depth of possible damage and hole depth were considered as dependent variables denoted by y_1 and y_2 respectively.

The copper material will be considered first and the simple linear regression equation of y_1 on x was performed. The slope and the intercept parameters of the line were found to be significantly different from zero. The coefficient of determination for the equation was 100%, which means absolute straight line[11].

$$y_1 = 0.226 + 0.006\,x \quad \dots (1)$$

Figure (1)shows the scatter plot of the data and the impel linear regression line that is the best fit for the data of these two variables. It is therefore, possible to predict the depth of possible damage in copper material if the number of pulses is given in advance.

The linear relationship between number of pulses and hole depth of copper material made is given in equation (2). This equation clearly shows that relationship between hole depth and number of pulses is not linear since the coefficient of determination was found to be 0.08 and both parameters of equation (2) are not significantly different from zero.

$$y_2 = 39.321 + 0.453\,x \quad \dots (2)$$

Figure(2) revealed that spline interpolant is the best fit for this set of data. The red line that represents equation (2) gives a fair idea about how bad is the linear representation ,i.e. equation(2)cannot be used for prediction purposes.

It is of interest to investigate whether hole depth can and depth of possible damage for copper material can be put in a form of linear relationship. Equation (3) shows this relation. In this equation both parameters are found to be not significantly different from zero and the coefficient of determination equals to 0.08. It is therefore can be concluded that the relation is far from linear. Figure (3) shows the scatterplot of the points as well as the fitted models[11].

$$y_2 = 22.506 + 74.394\,y_1 \quad \dots (3)$$

The above procedure was repeated in the same manner for the titanium material. In this context, equation (4) shows the simple linear regression line of depth of possible damage on pulse number.

$$y_1 = 54.972 - 3.606\,x \quad \dots (4)$$

Although the coefficient of determination equals 0.68, but the regression is significant and both parameters of the equation re significantly different from zero.

Figure (4) shows the scatter plot of the points of these two variables as well as the fitted models. It is clear the spline interpolant gives the best fitting.

The simple linear regression equation (5) of the depth hole on the number of pulses shows that the slope parameter is not significantly different zero. And that 53% of the regression line can be interpreted by the intercept[11].

$$y_2 = 64.209 - 3.201\,x \quad \dots (5)$$

Figure (5) shows the scatter plot of the points as well as the fitted models. The spline interpolnt is the best fitting for this set of data.

The simple linear regression line (equation 6) was found to the worst model fitted the data of linear regression y_2 on y_1 . Both parameters of the equation were to be not significantly different from zero.

$$y_2 = 28.721 + 0.018\,y_1 \quad \dots (6)$$

Figure(6) shows that neither the simple linear regression nor the quadratic model can fit this data. Many attempts were made to find the best fit for this set of data. The quadratic model, although it is worse but it is much better than the linear fitting.

Discussion

The variability of number of pulses propagated significantly affected the depth of possible damage and hole depth of materials (copper and titanium) considered in this study. It is worthwhile stating that the effect of pulses on the copper material behaved differently when compared to titanium. In the first case the damage increased steadily, whereas in the case of titanium started with high damage and tends to decreases with high pulse numbers. For this reason the linear relationship in the first was absolutely straight, whereas it wasn't the state for the second case.

The slope of the hole depth for both materials was not significantly different from zero, that is linear model is not suitable. The titanium material tend to have an approximately a fixed effect since the intercept parameter was found to be significantly different from zero, whereas it wasn't the state with regard to copper material.

In both materials, it was not possible to find a model that govern the relationship between the depth of possible damage and hole depth.

Conclusions

It is obvious from the all that the copper material is better than titanium in accordance with exploration the range of damage generated by pulsed laser in the field of a certain number of pulses .As for titanium, the behavior was different, this is may be due to the

characteristics of the used laser which not fit with the characteristics of titanium material. Thus we can take in consideration and examine titanium material to a different types of lasers in order to know the behavior of this material with the other kinds of lasers.
The study illustrated that the increment of number of pulses during certain periods leads to an essential damage on the materials with no care to the nature of response of the materials(linear or nonlinear) with the number of pulses.

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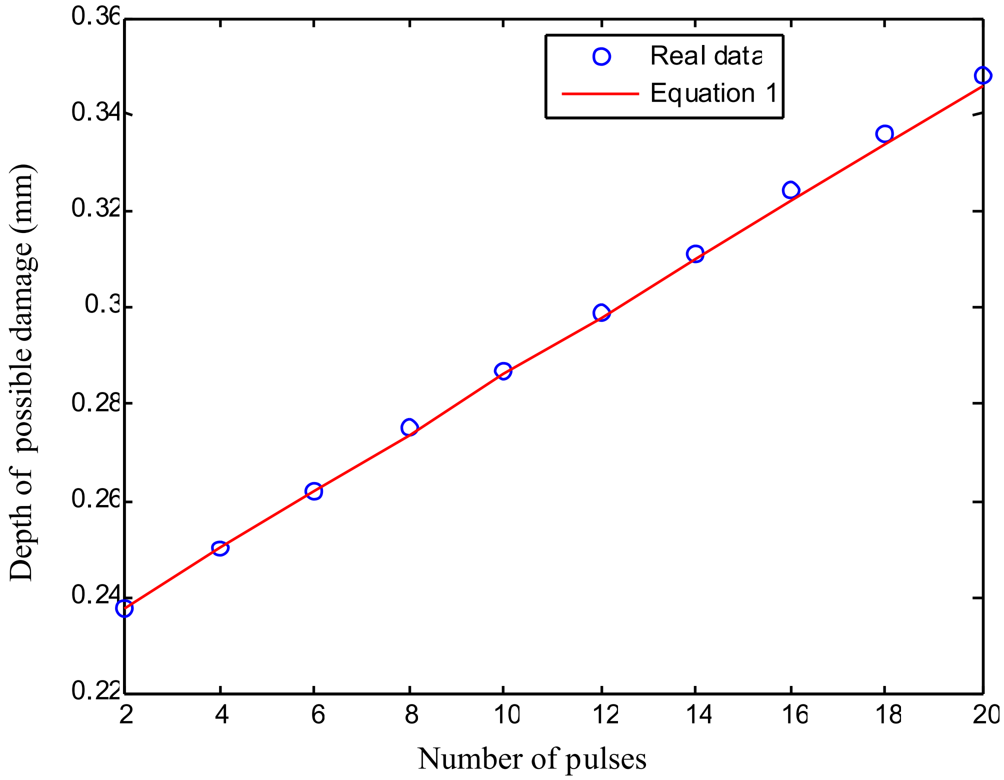

Fig.(1): Scatter plot and fitted equation for number of pulses and depth of possible damage (Copper)

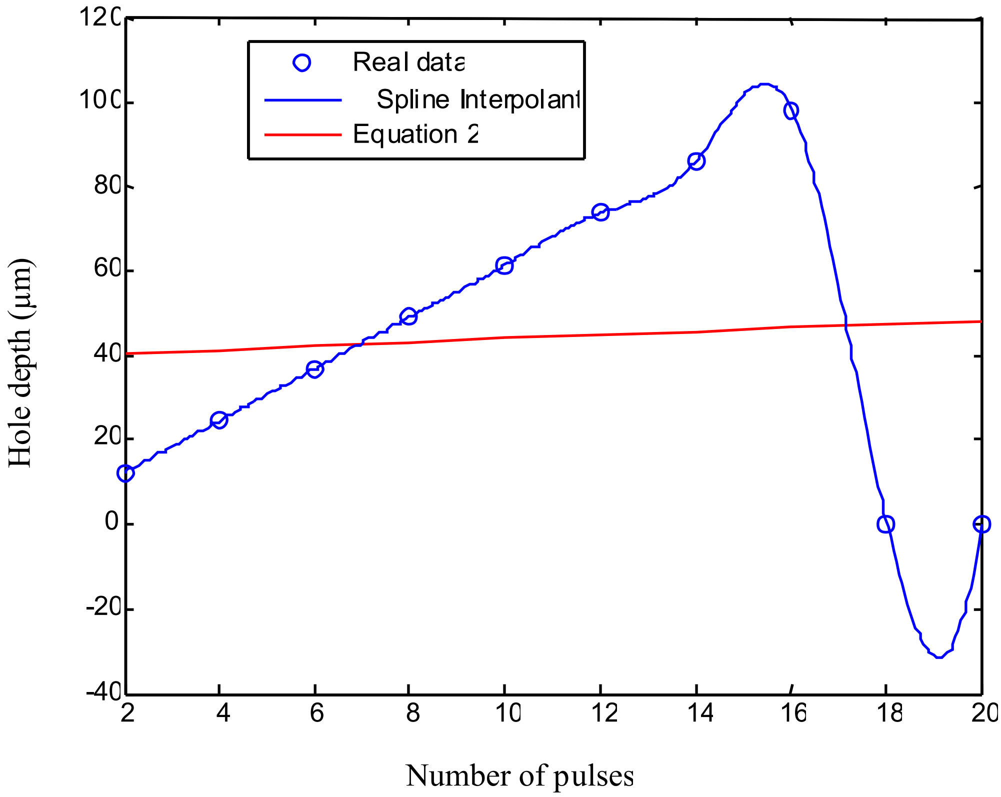

Fig.(2): Scatter plot and fitted equation for number of pulses and hole depth (Copper)

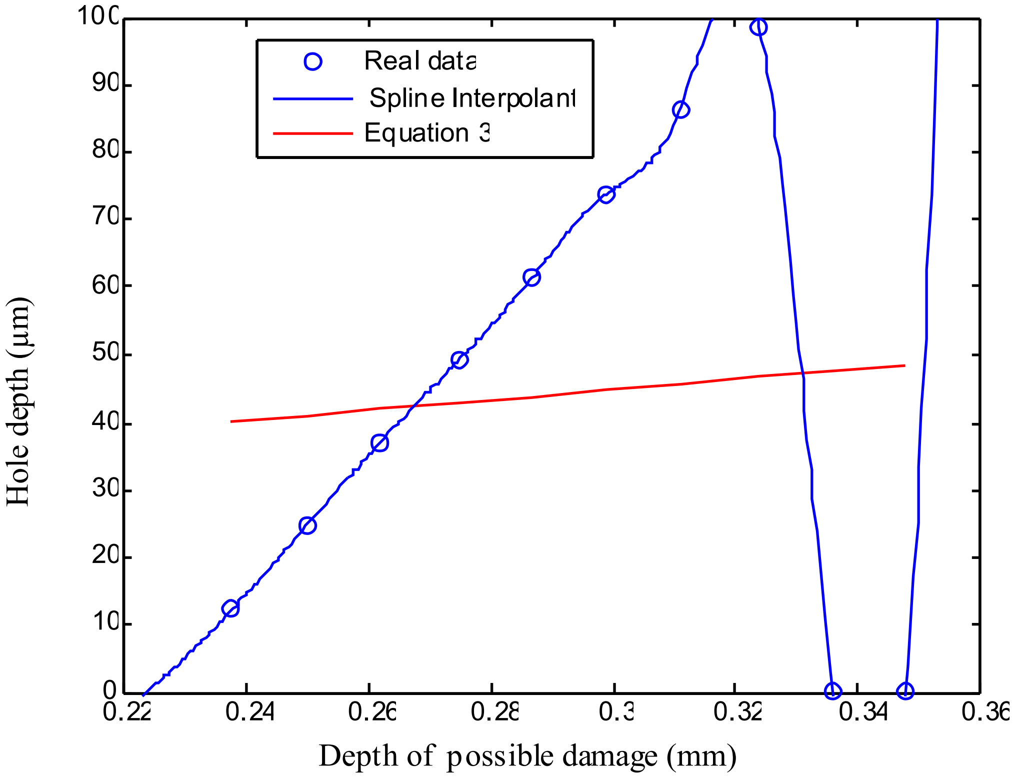

Fig.(3): Scatter plot and fitted equation for depth of possible damage and hole depth(Copper).

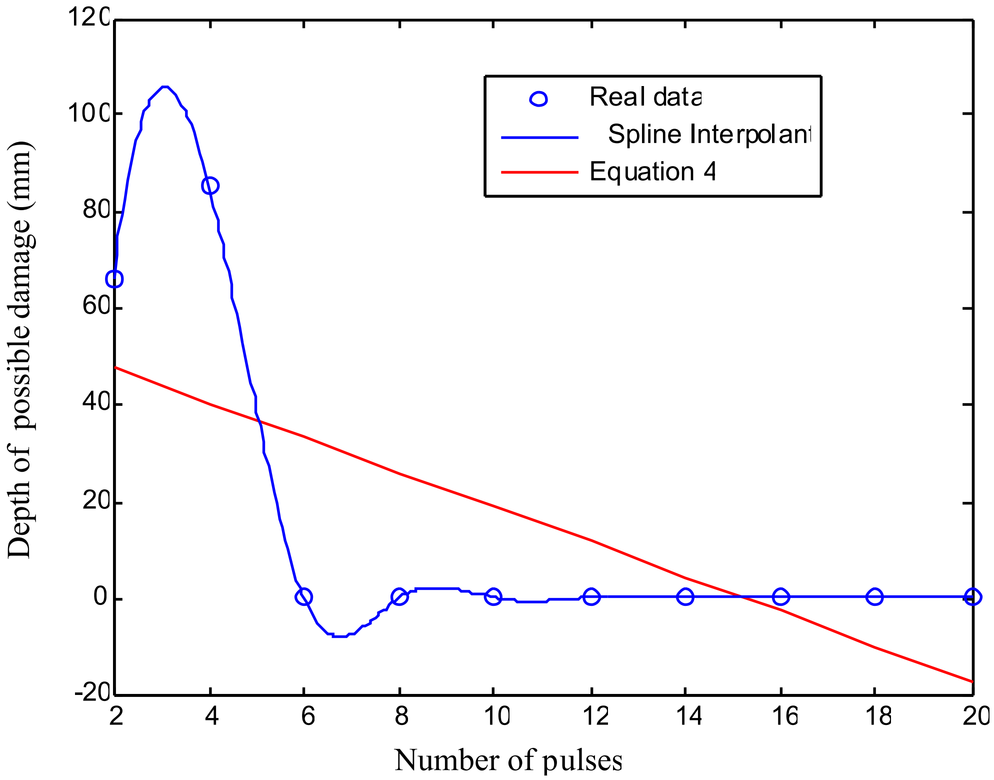

Fig.(4): Scatter plot and fitted equation for number of pulses and depth of possible damage (Titanium)

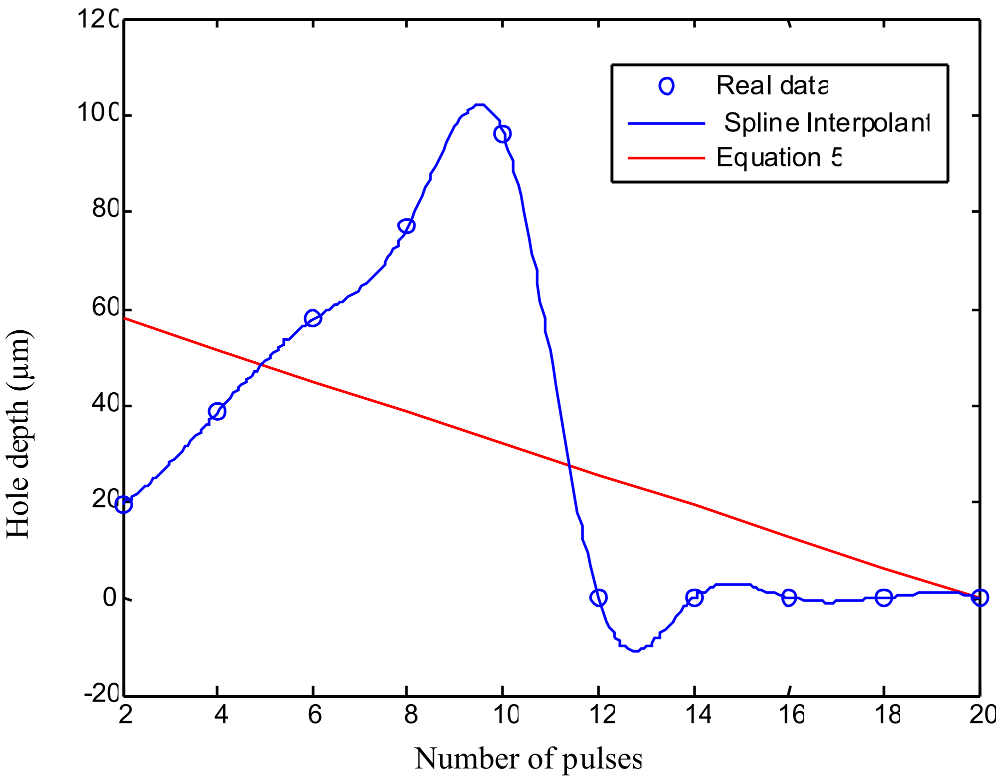

Fig.(5): Scatter plot and fitted equation for number of pulses and hole depth (Titanium)

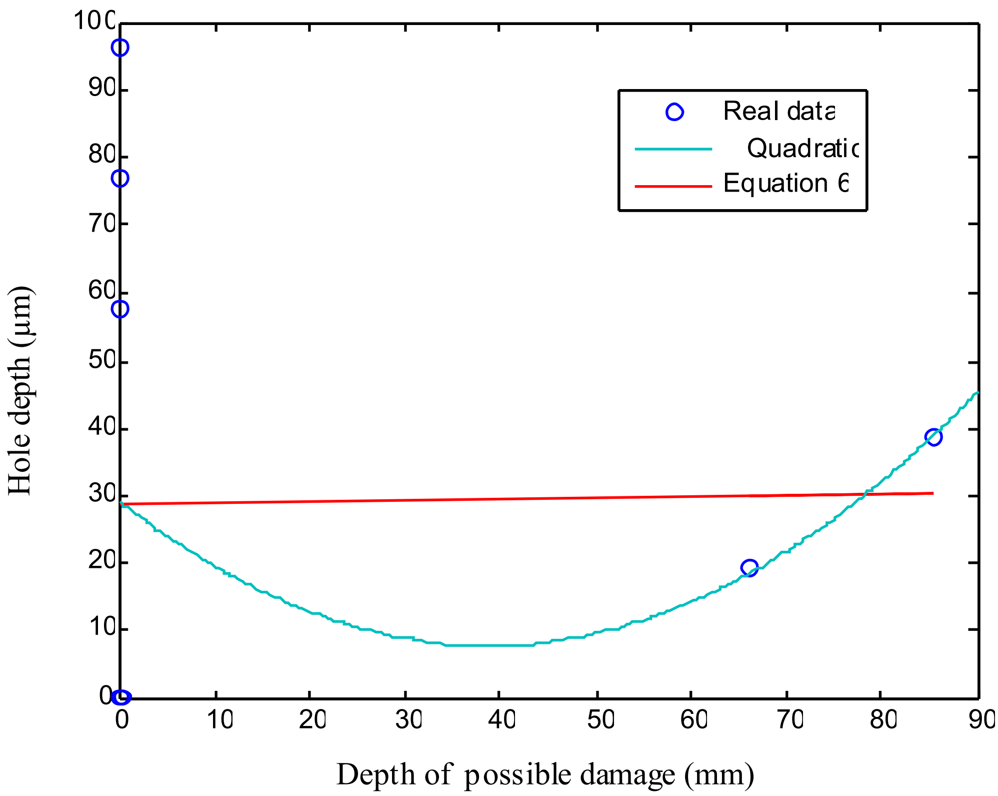

Fig.(6): Scatter plot and fitted equation for depth of possible damage and hole depth(Titanium)

الانموذج الرياضي لتأثير عدد نبضات الليزر النبضي في عمليات تشكيل البلازما

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الخلاصة

في هذا البحث أجريت دراسة تحليلية لتأثير عدد نبضات ليزر نبضي في المواد،فقد استخدمت نبضات مختلفة بزمن التأخير نفسه.في هذه الدراسة أخذ بنظر الاعتبار عمق التلف الممكن على سطح النحاس والتيتانيوم فضلا" عن إلى عمق الحفرة لكلا المادتين .لقد أظهرت الدراسة أن الانموذج الخطي يكون ممكنا فقط في حالة تقدير عمق التلف الممكن حصوله لمادة النحاس ،وهذا يعني ان عمق التلف الممكن يزداد مع زيادة عدد نبضات الليزر. بينما أظهرت الدراسة ان العلاقة تكون غير خطية بالنسبة الى مادة التيتانيوم.ان عمق التلف الممكن لمادتي التيتانيوم والنحاس يختلف، وأن مادة النحاس تبدو أكثر قابلية للتنبؤ بسلوكها من مادة التيتانيوم .

كلمات مفتاحية: الليزر النبضي،زمن التأخير،النماذج الخطية،النحاس.