Iraqi Journal of Physics, 2018 *Vol.16, No.36, PP. 47-52*

DOI: 10.20723/ijp.16.36.47-52

Nanosecond laser pulses for aluminum and copper drilling

Sumaya Jeleel and Walid K. Hamoudi

Department of Applied Sciences, University of Technology, Baghdad, Iraq

E-mail: wjuaini2007@yahoo.com

Abstract

Nd:YAG laser pulses of 9 nanosecond pulse duration and operating wavelength at 1.06 µm, were utilized to drill high thermal conductivity and high reflectivity aluminum and copper foils. The results showed a dependence of drilled holes characteristics on laser power density and the number of laser pulses used. Drilled depth of 74 µm was obtained in aluminum at 11.036×10^8 W/cm^2 of laser power density. Due to its higher melting point, copper required higher laser power density and/or larger number of laser pulses to melt, and a maximum depth of 25 µm was reached at 13.46×10^8 W/cm^2 using single laser pulse.

Key words
Nanosecond laser pulses, laser drilling, metals.

Article info.
Received: Jun. 2017
Accepted: Sep. 2017
Published: Mar. 2018

استخدام نبضات الليزر النانوية في تثقيب الالمنيوم والنحاس

سمية جليل ابراهيم و وليد خلف حمودي

قسم العلوم التطبيقية، الجامعة التكنولوجية، بغداد، العراق

الخلاصة

تم استخدام ليزر النيدميوم – ياك الذي يعمل بالطول الموجي 1.06 مايكرومتر والذي يعطي نبضات ليزرية بأمد 9 نانوثانية من أجل تثقيب رقائق الالمنيوم والنحاس ذي الانعكاسية والتوصيلية الحرارية العالية. أوضحت النتائج إعتماد خصائص الثقوب المنجزة على كثافة قدرة شعاع الليزر وعدد النبضات الليزرية. تم الحصول على عمق ثقب طوله 74 مايكرون في رقاقة الالمنيوم عند استخدام نبضة ليزر واحدة بقدرة ليزر (11.036×10^8) واط/سم٢. بسبب درجة الانصهار اللاعلي للنحاس فقد تم الحصول على عمق ثقب طوله 25 باستخدام نبضة ليزر واحدة بقدرة ليزر (13.46×10^8) واط/سم٢

Introduction

Drilling metals with lasers brings many advantages to this industrial practice. In addition to its localized and non-contact features, the process is associated with a very limited heat affected zone (HAZ). Laser drilling is capable of dealing with tough, high reflectivity and high vaporization temperature materials [1, 2]. In this process, heating, limited melting, vaporization and plasma formation take place. With microsecond laser pulses, laser power density of (10^6 W/cm^2) is required, but with nanosecond laser pulses, (10^8 W/cm^2) power density is almost the rule of thumb to drill metals without HAZ. At this high level of power density material ablation takes place. At nanosecond laser interaction regime with metals, material reflection is broken down at most infrared laser wavelengths and the absorption of metals will only depend on temperature. Total removal of copper coating was achieved by 10 ns Nd-YAG laser operating at second harmonic frequency with 532 nm wavelength using a laser energy density of (1 J/cm^2). Laser drilled holes; covered with re-solidification material and some cracks, were seen when using 8ns laser pulses from Ti: sapphire laser in the drilling of silicon

[3]. The ablation of bulk aluminum, bronze and copper was experimented using nanoseconds laser pulses. The ablated depth was found to decrease with the ablation rate [4]. Some mechanical and thermal damage was found with nanosecond pulses when using Q-switched Nd: YAG laser to drill silicon wafer [5]. High ablation rate with nanosecond pulses was achieved on some metals; but with evidenced thermal damage on the target [6]. The micromachining of metals, silicon, polymers and ceramics was achieved with high aspect ratio using high power density nanosecond laser pulses [7]. In the current work, nanosecond laser pulses were utilized to drill aluminum and copper. The idea is to freeze the metals' thermal conductivity by taking advantage of the fast nanosecond interaction time and achieve low thermal distortion drilling and this is an important issue for heat sensitive devises where the localized heat can maintain the device without destroy.

Experimental methods

Nd: YAG laser with 9 nanosecond and 0.5 Joule; supplied by DELIXI-China, was used to drill holes in aluminum and copper foils. Thin aluminum and copper foils as shown in the Fig.1 were cut into small squares (2×2) cm and cleaned with alcohol to remove dirt and grease contaminants.

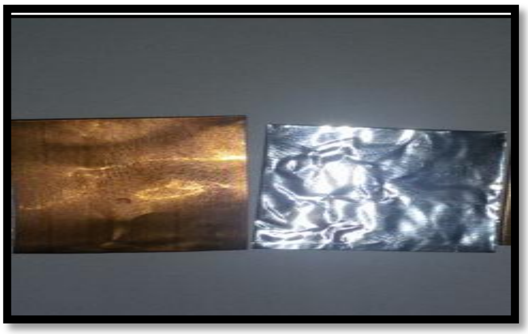

Fig.1: Aluminum and copper foils that used in this work.

No chemical or physical surface treatment was employed and the samples purity comes under "industrial grade" i.e. not so pure in order to demonstrate laser drilling on metals with specifications close to those used in real laser drilling. Simple experimental set-up was used as shown in the Fig.2 and the laser pulses were focused by 10 cm positive lens. Different values of laser energy and number of pulses were used to drill 0.08 mm aluminum and 0.04 mm copper foils. For these particular thicknesses, the thermal time constants are 20 μs and 16 μs for aluminum and copper respectively.

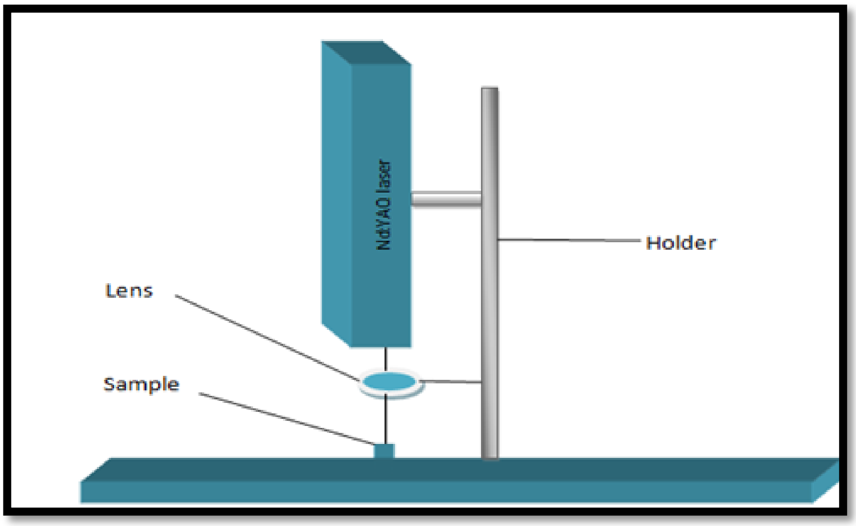

Fig.2: Experimental set-up used for drilling.

Results and discussion

Fig.3 shows a microscopic top view image of 18 μm hole; drilled in aluminum by a 100 mJ (8.2×10^8 W/cm^2) laser pulse. Fig.4 illustrates a relation between laser intensity and drilled depth; reaching a value of 74 μm at 140 mJ (11.03×10^8 W/cm^2**)**. At higher power densities, vapor and ejected re-condensation increases to limit any further increase in the drilled depth.

Fig.3: Top view image of a hole drilled in aluminum (100X) by 100 mJ laser pulse.

High laser power densities cause partial vapor ionization and molten re-solidification; making the depth increase exponential. The relationship between laser power density that used and hole diameter is presented in Fig.5. Small diameter holes are produced at lower laser energies (low power density). At higher laser energies, the beam diverges and larger hole-diameters are produced. Without using any processing gas, black and rough area around the hole is seen. This originates from splashing burnt impurities in the metal; a finding that agrees with published work [8]. This figure shows no cracks; in favor of our hypothesis of reducing thermal and mechanical damage by laser processing with pulses shorter the thermal time constants of the metals.

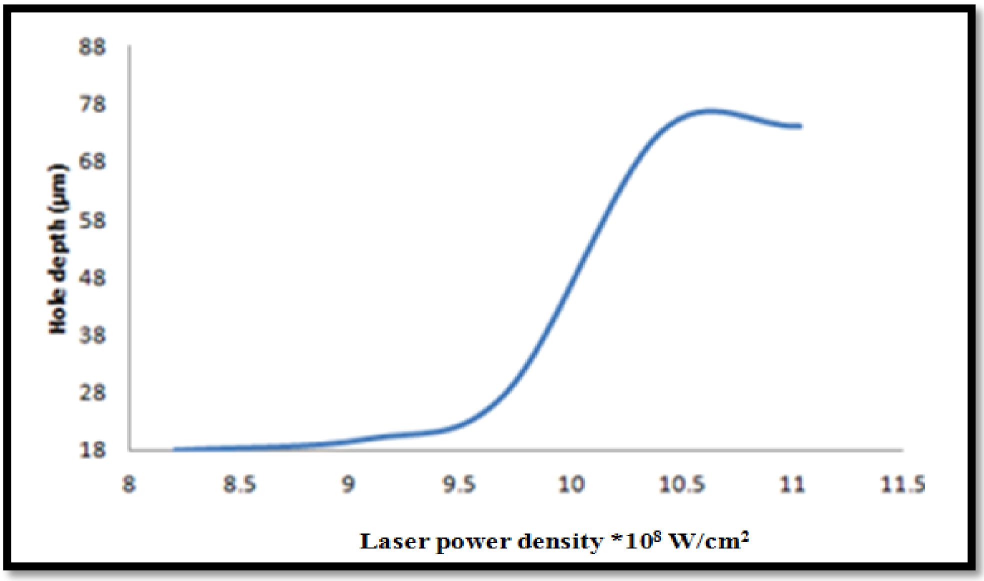

Fig.4: Laser-drilled depth in aluminum against laser power densities.

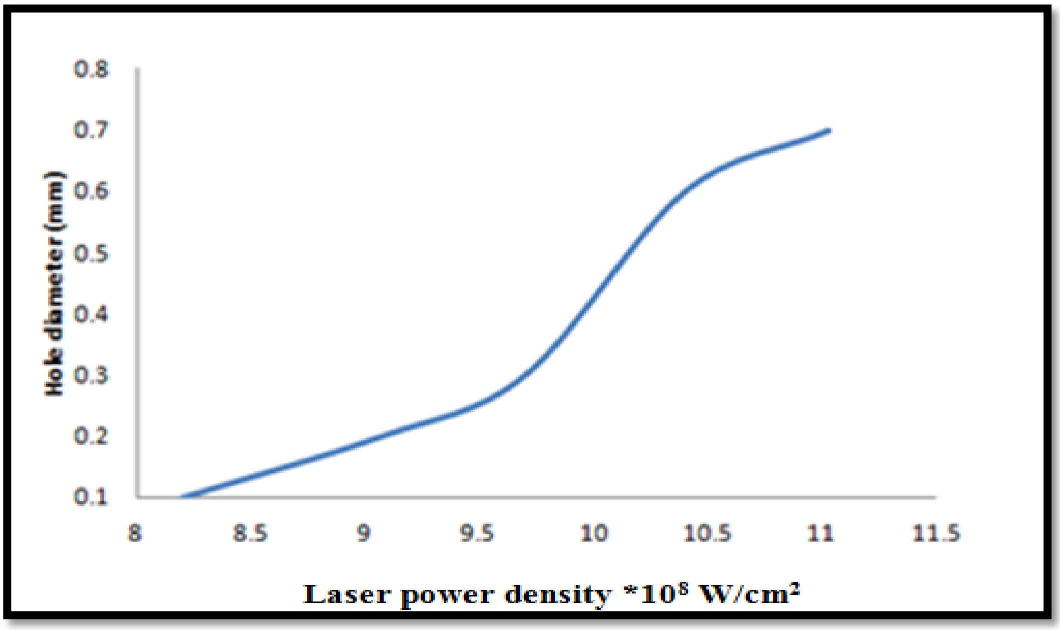

Fig.5: Laser power density versus drilled diameter in aluminum.

Because of its small thickness, the aluminum sheet was drilled fully by a single laser pulse of (8 × 10^8 W/cm^2) laser power density. Table 1 illustrates the aspect ratio (depth/ diameter) when drilling aluminum with different laser intensities. Fluctuation of aspect ratio values could have resulted from inhomogeneous aluminum structure or/and fluctuation of the mains supply which affected emitted laser energy. The crater diameter increased with the laser energy; in agreement with published work [9].

Table 1: Aspect ratio of drilled holes depth in aluminum at variable laser power densities.

Laser power density × 10^8 (W/cm^2)	Aspect ratio
8.2	0.105
9.07	0.121
9.7	0.093
10.4	0.1
11.03	0.18

The graph between the number of laser pulses versus depth in copper is shown in Fig. 6. 32 µm depth was produced by 6 laser pulses, using (13.46×10^8 W/cm^2) laser power density.

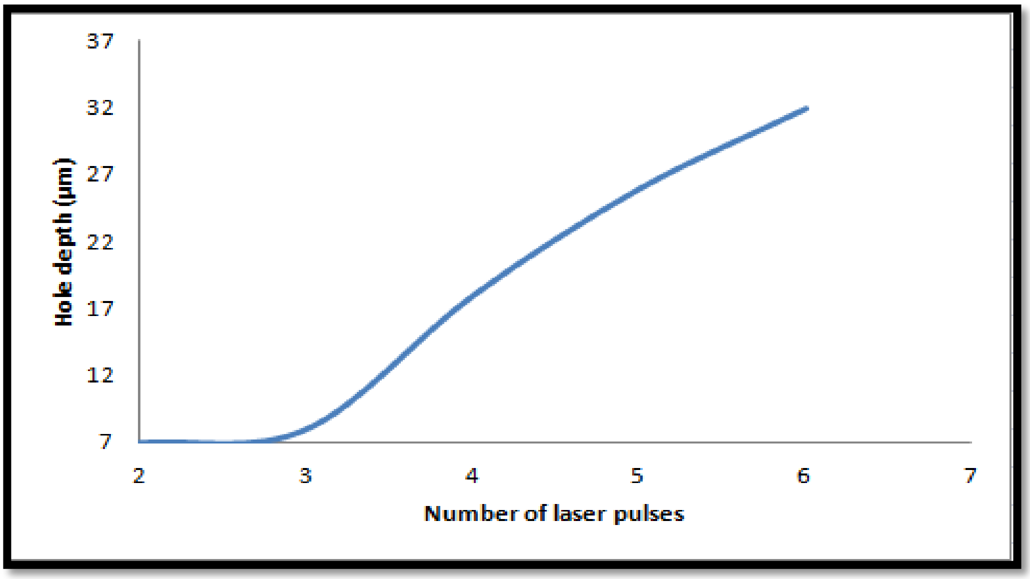

Fig.6: Hole depth against number of laser pulses in copper.

Fig.7 shows microscopic top view images of copper samples drilled by a single laser pulse, using (13.46 $\times 10^8$ W/cm^2) laser power density. The debris and splashing around the hole is seen because no processing gas was used to remove the ejecta. The relationship between laser power density and drilled depth is shown in Fig.8. Depth increases took place with increasing laser power density and maximum depth of 25 μm was reached at 13.46$\times 10^8$ W/cm^2; using a single laser pulse. This result agrees with published literature [10]. Comparing Fig.4 with Fig.8, copper has higher boiling temperature than aluminum; and therefore required higher laser energy and/or larger number of laser pulses to remove similar depth. For nearly same range of laser power densities, smaller hole depths were obtained in copper than in aluminum.

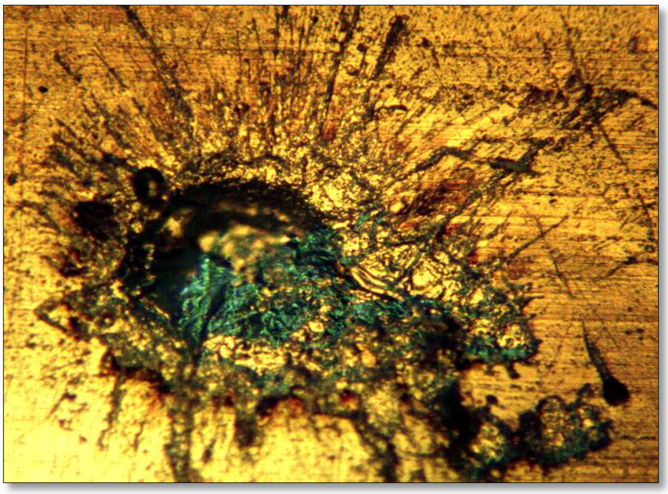

Fig.7: Laser drilling of copper foil by single laser pulse, (100X).

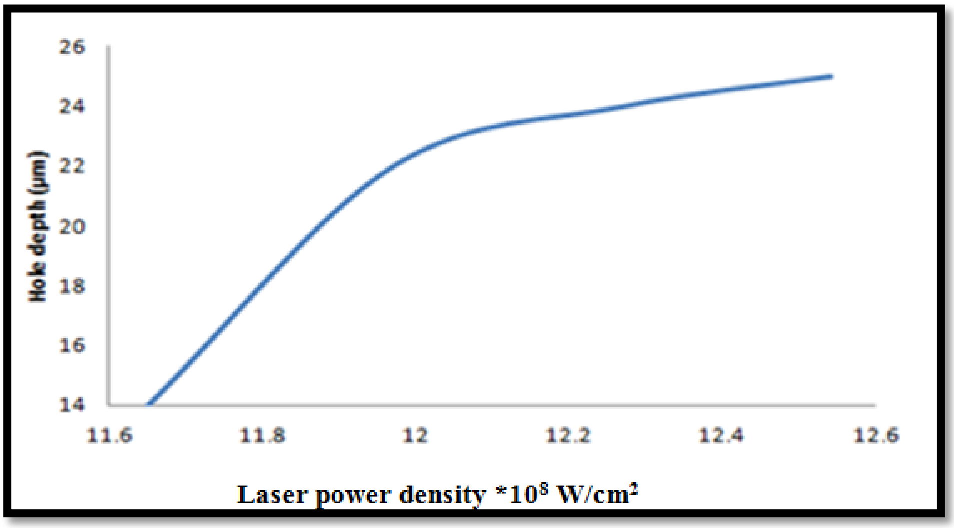

Fig.8: Hole depth increase with laser power density in copper.

Conclusions

Holes were drilled or ablated in aluminum and copper sheets by using different values of laser energies from Q-switched Nd: YAG laser. Linear increase in holes depth occurred with laser energy increase; reaching a value of 74 μm at 140 mJ for aluminum and 25 μm for copper. Small diameter holes were produced at high levels of laser power density. The rate of hole depth increase was found to decrease with increasing the number of laser pulses.

References

[1] S. B. Matthew and B. A Craig, Chapter four, Springer series in materials science, 135.pp 91-101 (2010).

[2] F. R John, "Industrial applications of lasers", Second edition, Academic Press, San Diego, CA 92101-4495, USA. (1997).

[3] J. Kaspar, A. Luft, S. Nolte, M. Will, E. Beyer, Journal of Laser Applications, 18, 2 (2006) 85-92.

[4] R. Maisterrena-Epstein, S. Camacho-López, L. Escobar-Alarcón, M. Camacho-López, Sociedad Mexicana de Ciencia y Tecnología de Superficies y Materiales, Superficies y Vacío 20, 3 (2007) 1-5.

[5] Henrikki Pantsar, Hans Herfurth, Stefan Heinemann, Petri Laakso, Raimo Penttila, Yi Liu, Golam Newaz "Laser Micro via Drilling And Ablation Of Silicon Using 355 nm Pico And Nanosecond pulses" ICALEO 2008, Paper M507, Laser Micro-processing Conference, (2008).

[6] Karl-Heinz Leitza, Benjamin Redlingshöfer, Yvonne Reg, Andreas Otto, Michael Schmidt, Physics Procedia, 12 (2011) 230–238.

[7] R. Pragada, M. V. Kumar, P. Gangaraj, International Journal of Emerging Technology and Advanced Engineering, 3, 4 (2013) 294-298.

[8] Uroš Trdan, José Luis Ocaña, Janez Grum, "Surface Modification of Aluminum Alloys with Laser Shock Processing" Journal of Mechanical Engineering, 575 (2011) 385-393.

[9] Ionut, Vlădoiu, Mihai Stafe, Constantin Neguţu, Ion M. Popescu, U.P.B. Sci. Bull., Series A, 70, 4 (2008) 119-126.

[10] A. Weck, T.H.R. Crawford, D.S. Wilkinson, H.K. Haugen, J.S. Preston, Author's personal copy - Published in Applied Physics, A 90 (2008) 537-543.