Thin Films Ablation by Induced Forward Transfer Technique

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ABSTRACT

Laser-Induced Forward Transfer (LIFT) is a technique which enables the controlled transfer of a thin film material from a transparent carrier (donor) to a receiver substrate (acceptor). The receiver substrate is usually placed in parallel and close to the thin film source under air or vacuum conditions. In this work microdeposition of gold (Au) and Copper (Cu) thin films were deposited on glass substrate by Pulsed Laser Deposition (PLD). These thin films were irradiated by a single pulse and transferred to a silver (Ag) and silicon (Si) receiver substrates. The laser source used for this study was a Nd-YAG Q-Switching second harmonic generation (SHG) Pulsed Laser with a wavelength 532nm, repetition rate 1-6 Hz ,and pulse duration 10ns. Deposited size, morphology and adhesion to the receiver substrate as a function of applied laser fluence are investigated.

إزالة الاغشية الرقيقة باستخدام تقنية انتقال الليزر المحتث المباشر

الخلاصة

الانتقال الامامي المحتث بالليزر هو تقنية تسيطر على انتقال جزء من الغشاء الرقيق للمادة من الحاملات الشفافة (الواهبة) الى القواعد المستلمة (القابلة) ،وعادة ما توضع القواعد المستلمة بموازاة وبالقرب من الغشاء الواهب وتتم العملية في الجو او تحت ظروف الفراغ. في هذا البحث تم ترسيب اغشية رقيقة من معدني الذهب والنحاس على قواعد من الزجاج (الواهبة) بواسطة الترسيب بالليزر النبضي . تم تسليط نبضات منفردة على هذه الاغشية وتم نقلها الى قواعد من الفضة والسليكون. مصدر الليزر المستخدم في هذه الدراسة هو ليزر النيديميوم- ياك يعمل بنمط التولد التوافقي الثاني(بطول موجي 532نانومتر و تكراريـــة 1-6 هرتــز وآمـــد نبضـــة 10 نانوثانية) حجم الغشاء المرسب على القاعدة المستلمة ، طوبوغرافية السطح ،وقوة الالتصاق بين الغشاء والقاعدة المستلمة تم دراستها كدالة لكثافة طاقة الليزر المستخدم.

INTRODUCTION

Laser-induced forward transfer (LIFT) is a direct-writing technique that allows depositing tiny amounts of material from a thin film (deposited onto a transparent holder) to a receptor substrate by means of the action of a laser pulse. The technique was initially developed to transfer inorganic materials from precursor solid films [1-3] and its mechanism of operation consisted in the complete vaporization of a small portion of the film and further recondensation of the vapor onto the receptor substrate in the form of a solid dot. However, it was later shown that transfer was also possible from pastes and liquids [4,5]. In these cases, the transfer mechanism appeared to be different, instead of being vaporized, a small volume of paste or liquid was directly ejected from the holder under the action of a laser pulse, and the material preserved its paste or liquid nature once deposited onto the receptor substrate. LIFT has been successfully applied for the direct-writing of metals [1, 6-12], polymers [13], oxides [14,15], superconductors [16], diamond [17], carbon nanotube field emission cathodes [18] conducting polymers [19]. Realizing the transfer while the supporting carrier and the receiving substrate can be moved with respect to each other, it allows the production of micrometric scale patterns of many different materials and components on diverse substrates. The material to be transferred is initially deposited in thin films on a transparent substrate named donor substrate, or "ribbon" (transparent at laser radiation used for LIFT process). The donor film is irradiated backward with a pulsed laser. The laser is focused on the donor thin film at the interface with the donor substrate. Then, a small amount of buffer material is ablated and transformed in gaseous phase. This gas expands pushing forward the rest of the material which is projected to the acceptor substrate [20]. The type of laser (i.e. its wavelength, the laser wavelength is selected to the range of minimum carrier absorption and maximum film absorption, intensity, and focal spot size), the type of the material (i.e. optical absorption coefficient, thermal diffusivity) and the geometry of all components determine the quality of the transferred material arrives onto substrate [21]. Usually, the receiving substrate is placed in parallel and at a close proximity to the thin film source under air or vacuum conditions. In the present work, microdeposition of Au and Cu thin films were deposited on glass substrate by PLD. These thin films were transferred to Ag and Si substrates. Morphology and adhesion to the receiver substrate as a function of applied laser fluence were investigated.

THEORETICAL MODEL

The LIFT process involves the following three sequence events [22]. As shown in Fig. (1).

a) The laser pulse vaporizes the surface layer causing the vaporization and expansion of the plasma and the propagation of the shock wave in the material (Ablation).

b) High velocity (V_f) of the thin film (Transfer).

c) Impact with the substrate and the creation of hot regions between the thin film and the substrate (Deposit).
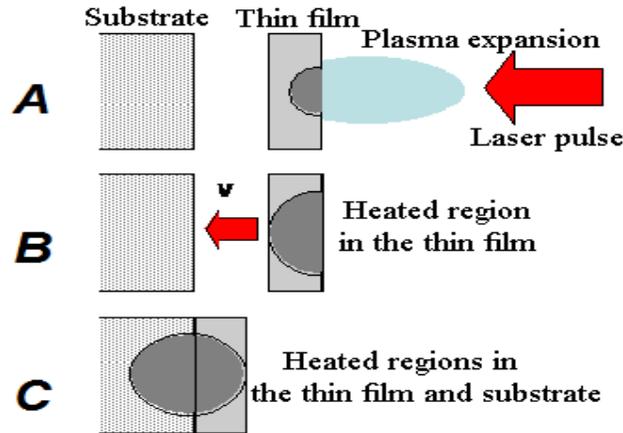
Figure (1) Process of the LIFT

The shock wave is generated in the thin film material in response to the expansion of the plasma towards the laser. In literature, the phenomenon has been extensively studied and the pressure of the shock has been linked to the characteristics of the laser through the following relationship:

$$P(Mbar) = 8.6 \left(\frac{I}{10^{14}}\right)^{2/3} \lambda^{-2/3} \left(\frac{A}{2Z}\right)^{1/3} \qquad (1)$$

Where I (W/cm^2) is the laser intensity, λ (μm) is the wavelength and Z is the number of atoms.

The speed of propagation along the thickness of the thin film determines the time required for the shock to occur as shown in figure (1) (B).

Once the wave pressure arrives at the face thin film will start to go eventually to impact with the receptor substrate as shown in figure (1) (C) The speed of the thin film can be estimated as follows:

$$v_f = \frac{p\tau}{\rho_0 d'} \qquad (2)$$

Here should be considered that the mass of the thin film set in motion does not correspond to the initial thickness (d) but at a thickness d '<d are a certain thickness is evaporated just as laser ablation effect and the production of plasma.

This thickness can be estimated as follows:

$$d_{abl} = \frac{m\tau}{\rho_0} \qquad (3)$$

Then d '= d-d$_{abl}$ is the thickness of the thin film remained after ablation, d$_{abl}$ is the ablated thickness, ρ_0 is the initial density of the thin film, τ is the pulse duration and quantity (m) is the rate of ablated mass. The amount of ablated mass depends only on its intensity (I) and wavelength (λ) of the laser using the following formula.

$$m = 150 \left[\frac{I}{10^{14}}\right]^{1/3} \lambda^{-4/3} \qquad (4)$$

EXPERIMENTAL WORK

The experiments were all prepared using the setup composed of the optical

elements in Fig. (2) which consisted of a pulsed Nd:YAG laser (532 nm wavelength, 10 ns pulse duration and 1-6 Hz repetition rate), a pinhole, mirrors, attenuator, 10x microscope objective lens, donor and receiving substrates and translation system . The donor consisted of an optically transparent glass slides (3×2) cm^2 that has been coated, via pulsed laser deposition processing techniques, with either Au or Cu (thickness133-145nm) respectively. The substrates were first cleaned in distilled water in order to remove the impurities and residuals from their surface, then cleaned in alcohol. In this work, silver and silicon substrates are used as a receptor substrates. The samples were mounted on a mechanically controlled with two translation axes to expose a new area of the film at each laser pulse. The maximum laser fluence applied to the targets was ≤ 40 J/cm^2. The donor was placed in parallel, very close to the receiving substrates (distance of about 100 µm). All experiments were performed in air at room temperature. The characterization of the transferred films was performed using scanning electron microscopy SEM and Energy dispersive analysis of x-rays EDAX.
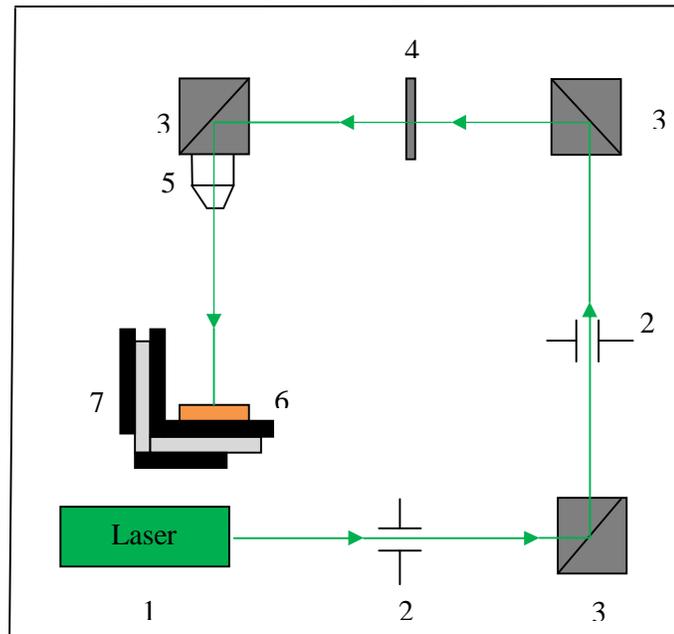

Figure (2) Scheme of the Laser Induced Forward Transfer setup.
1. Laser source,2. Pin hole,3. Mirror, 4. Attenuator,5.Objective lens,6.The sample,7. XY translation system,

RESULTS AND DISCUSSION

Optical microscope images of Au deposited on Ag at different laser fluences (10, 20, 30 and 40 J/cm^2) are shown in Fig. (3). While Fig. (4) represented the optical microscope images of Cu deposited on Si at the same fluencies. Fig. (3) a,b and Fig. (4) a,b showed a good uniform deposited spot. The spot shape is close to the laser spot size, good amount of deposited material, suitable crater. While in Fig.

(3) c,d and Fig. (4) c,d there was ununiformed deposition and less adhesion to the receiver substrate. The crater on the substrate surface is made by the high laser fluence. The morphology of deposition was checked using a Scanning Electron Microscope (SEM) as shown in Figs. (5, 7) On the other hand evidences for deposition of micrometric scale materials was normally checked using a quantitative analysis provided by the micro energy dispersive analysis of x-rays EDAX As shown in Figs. (6, 8). Fig. (9) represented the relationship between the diameter of the deposited dots and the laser fluence for Au on Ag and Cu on Si. In particular, it was observed with the naked eye that forward transfer of Au was induced and Au deposited on the Ag surface. Adhesion of the deposited film was very good. It was not possible to remove it from the Ag or Si substrates even when applying a sticking tape (the so-called "tape test" is simple but largely used to test the adhesion of deposited films). This result seems to be encouraging about LIFT technique as a possible approach satisfying the needs of jewelers industry. The influence of the laser energy density on the features of the deposition process is experimentally studied with the aim of improving the deposited patterning. At fluences just above the threshold, the absorbing thin films can be heated above its decomposition temperature, during a laser pulse results in a forward transfer of the thin film. It is important to know the minimum laser fluence needed to produce the transformation of material from thin film to the substrate provided that no damage (crater) is introduced into the substrate. Furthermore, it is important to produce a uniform deposition having almost the shape and dimensions of the laser focal spot. Optical microscope, SEM and EDAX analysis of our experimental results show that LIFT enabled the controlled transfer of thin films of several materials to receiving substrates using single laser pulses. We observed that the laser fluence significantly affected the process.
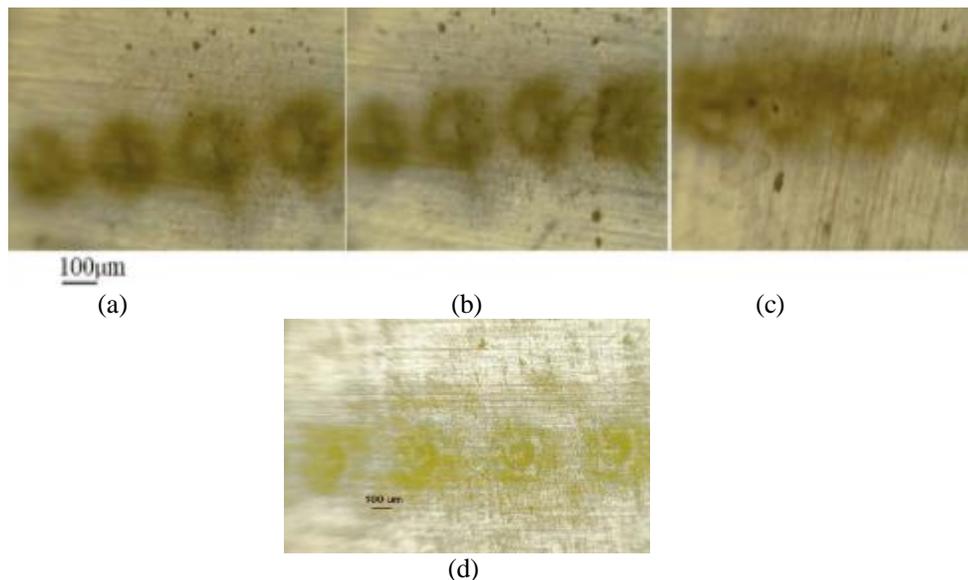

100μm

(a)   (b)   (c)

(d)

Figure (3) Optical Microscopy images of Au thin film on Ag substrate deposition at different laser fluencies: (a) at 10 J/cm^2, (b) 20 J/cm^2, (c) 30 J/cm^2 and (d) 40 J/cm^2.

(a)

100μm

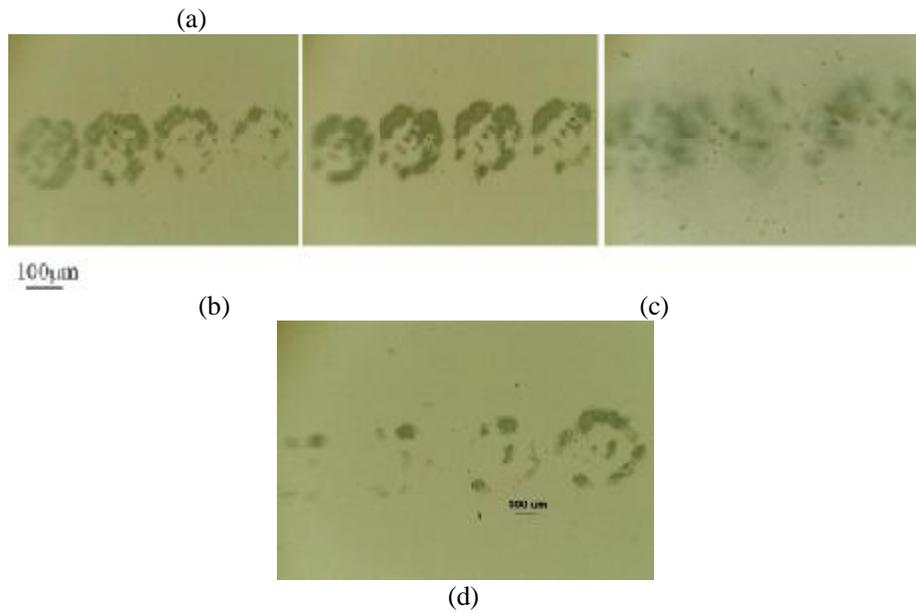(b)   (c)

(d)

Figure (4) Optical Microscopy images of Cu thin film on Si substrate deposition at different laser fluencies: (a) at 10 J/cm², (b) 20 J/cm², (c) 30 J/cm² and (d) 40 J/cm².
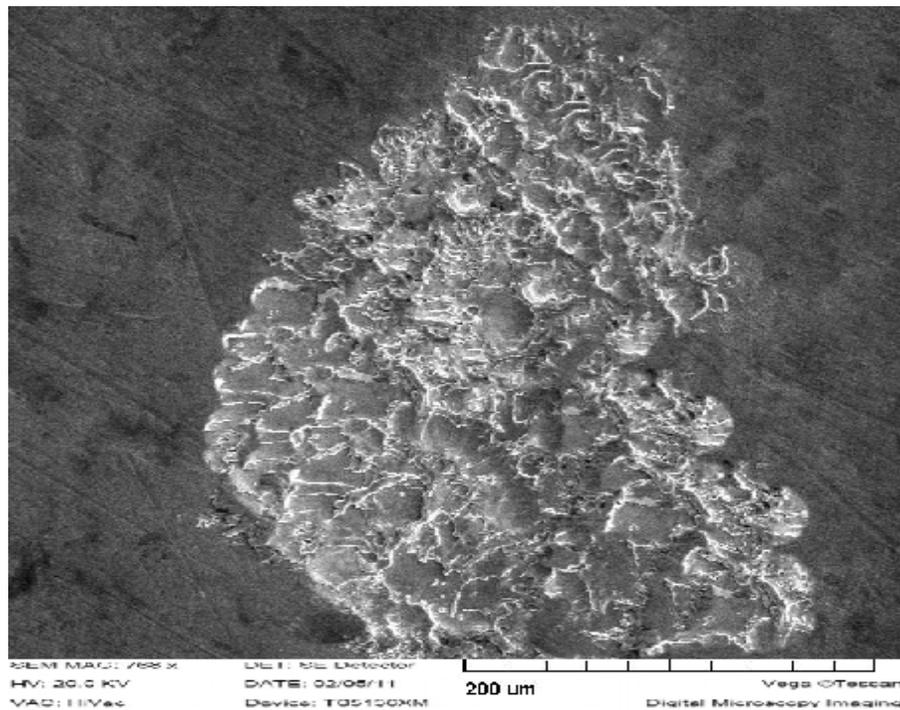

Figure (5) SEM image of Au thin film on Ag substrate.

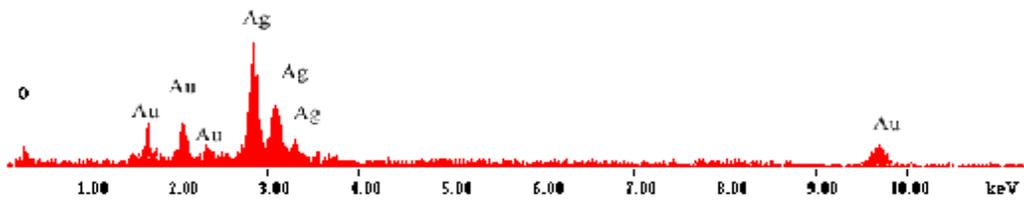1410

c:\edax32\genesis\genspe.spe

Label A:

Figure (6) EDAX spectrum of the deposition of Au thin film on Ag substrate.
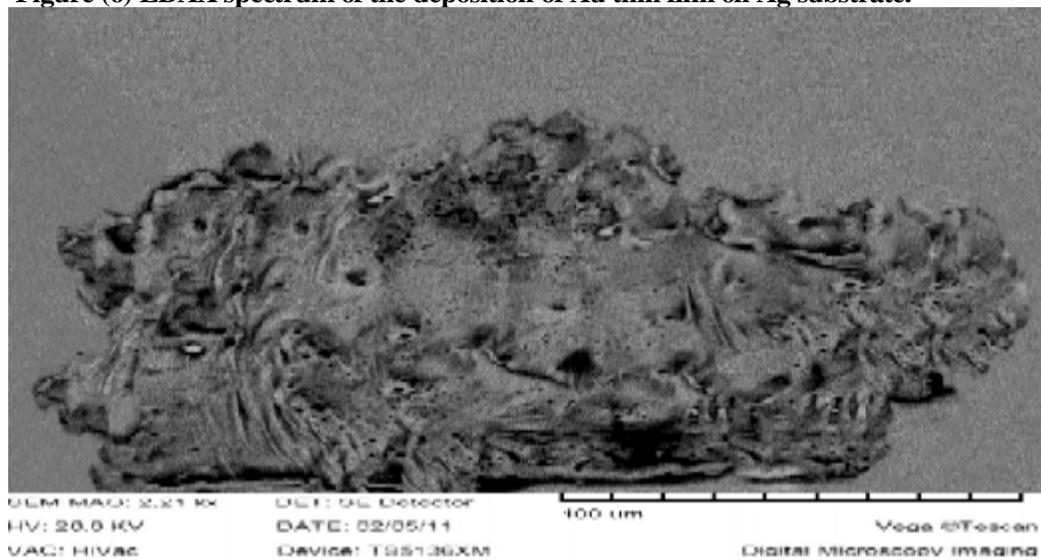

Figure (7) SEM image of Cu on Si substrate.

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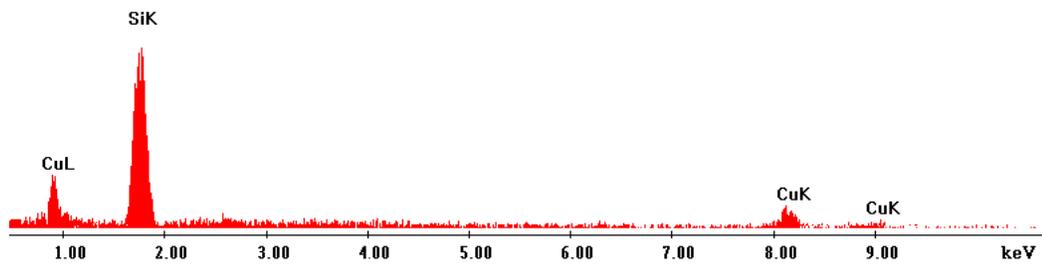
Label A:

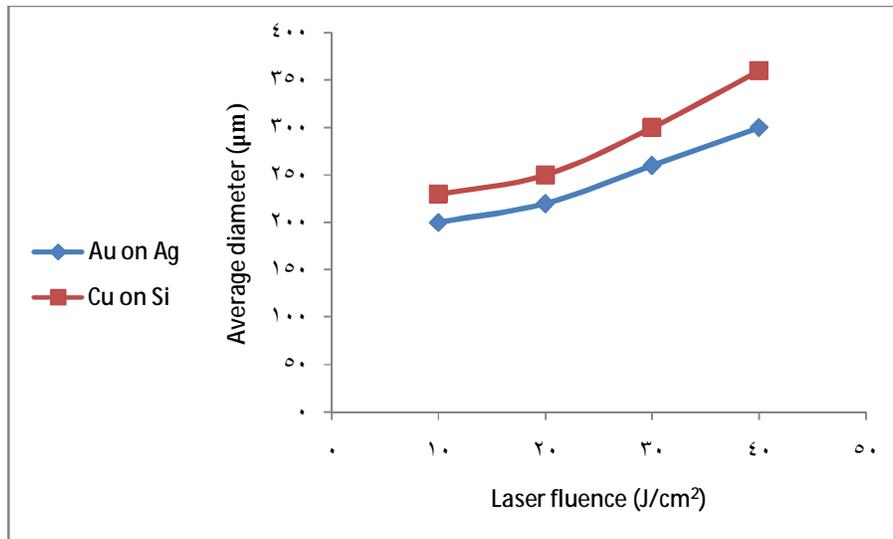**Figure (8) EDAX spectrum of the deposition of Cu thin film on Si substrate.**

Figure (9) Diameter of the deposited dots plotted as a function of the laser fluence for Au on Ag and Cu on Si.

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CONCLUSIONS

The variation of laser fluences and the corresponding morphological characterization of the deposited material have revealed that:

There exists a laser energy density range in which well-defined and circular microdots can be transferred. Within this range, the diameter of the deposited dot presented a linear relationship with the laser energy density. Therefore, controlling the irradiation conditions allows obtaining dots of different diameters. On the other hand, below this range no material is deposited, whereas above this range only irregular dots with satellites or splashing are obtained. It is possible to have good adhesion of precious metals onto another precious metals (Au on Ag), these results seems to be encouraging when using LIFT technique as a possible tool in jewelers industry.

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