Transfer of Metal Thin Films by Laser Induced Forward Technique

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Abstract

In this work preparation and characterization of Aluminum thin films by laser induced forward transfer has been studied. These thin films were deposited by thermal evaporation on glass substrates as donor substrates. 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 LIFT process 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 the applied laser fluence are investigated.

Keywords: LIFT process, Nd: YAG Q-Switching (SHG), Micro-ablation, Micro-deposition.

Introduction

Laser-induced forward transfer (LIFT) is a versatile direct-write technique in which a variety of functional materials can transferred from a donor substrate to a receiving substrate with high spatial resolution[1]. The technique was initially developed to transfer inorganic materials from precursor solid films [2-4] 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[5,6]. 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 can be used for the deposition of defined patterns of high lateral resolution, of a wide range of materials, onto a wide range of substrates[7]. The LIFT process has been successfully used to produce patterns of different biomaterials including proteins, DNA, living cells, tissues[8] and bacteria[9], polymers[10], carbon nanotube field emission cathodes[11] conducting polymers[12]. LIFT process is an indispensable technology for various applications including biosensor fabrication[13], gas sensors[14]. 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[15]. The type of laser, the type of the material and the geometry of all components determine the quality of the transferred material arrives onto substrate[16]. 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 Al thin films were deposited on glass substrate by thermal evaporation. These thin films were transferred to Ag and Si substrates. Morphology and adhesion to the receiver substrate as a function of the applied laser fluence were investigated.

Experimental Work

The experiments were all prepared using 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 as shown in Fig.(1). The donor consisted of an optically transparent glass slides (3×2) cm^2 that has been coated, via thermal evaporation technique, with Al (150nm) thickness. 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 ≤ 30 J/cm^2. The donor was placed in parallel, very close to the receiving substrates (distance of about 100 µm using aluminum sheets). All experiments were performed in air at room temperature. The characterization of the transferred films was performed using scanning electron microscopy SEM, Energy dispersive analysis of x-rays EDAX and optical microscopy.

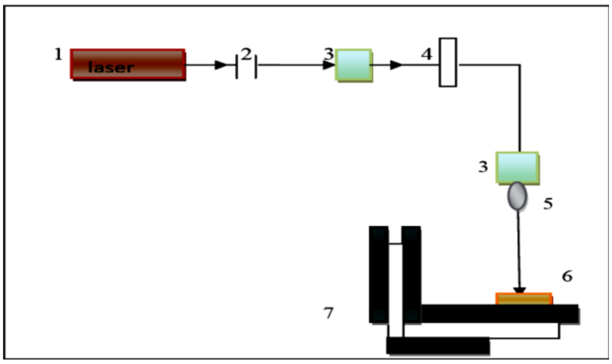

Fig.(1): Scheme of Laser Induced Forward Transfer setup
1. Laser source 2. Pinhole 3. Mirror 4. Attenuator 5. Objective lens 6. Sample (donor & receiver) 7. XY translation system.

Results and Discussion

Optical microscope images of Al deposited on Ag at different laser fluences (10, 20 and 30 J/cm^2) are shown in Fig.(2). While Fig.(3) represented the optical microscope images of Al deposited on Si at (10, 20 and 30 J/cm^2) fluences. Fig.(2) a,b and Fig.(3) 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.(2) c and Fig.(3) c 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.(4,6). 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.(5,7). Fig.(8) represented the relationship between the diameter of the deposited dots and the laser fluence for Al on Ag and Al on Si. In particular, it was observed with the naked eye that forward transfer of Al was induced and Al deposited on the Ag and Si surfaces. Adhesion of the deposited films 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). 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.

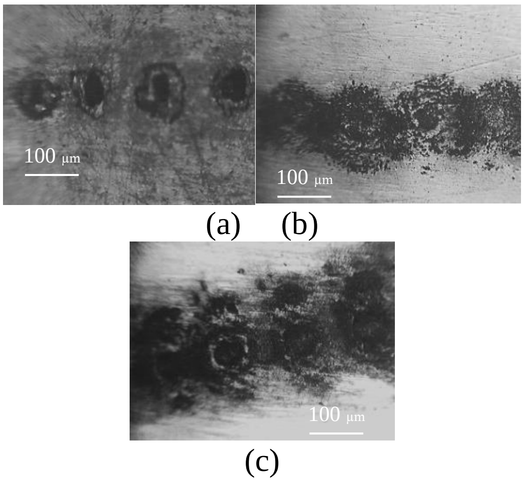

Fig.(2): Optical Microscopy images of Al thin film on Ag substrate deposition at different laser fluencies: (a) at 10 J/cm^2, (b) 20 J/cm^2 and (c) 30 J/cm^2.

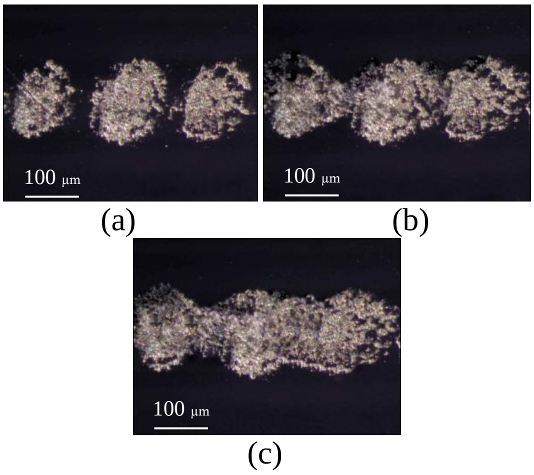

Fig.(3): Optical Microscopy images of Al thin film on Si substrate deposition at different laser fluencies:
(a) at 10 J/cm^2, (b) 20 J/cm^2 and (c) 30 J/cm^2.

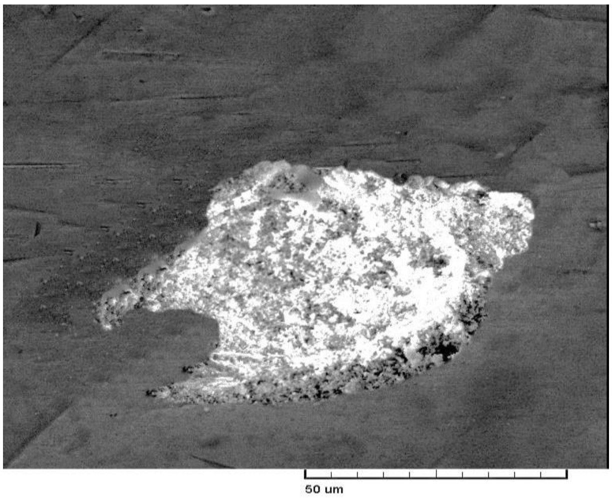

Fig.(4): SEM image of Al thin film on Ag substrate at 10 J/cm^2.

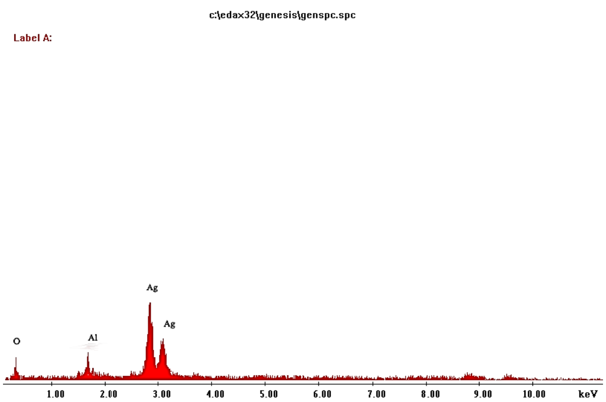

Fig.(5): EDAX spectrum of the deposition of Al thin film on Ag substrate.

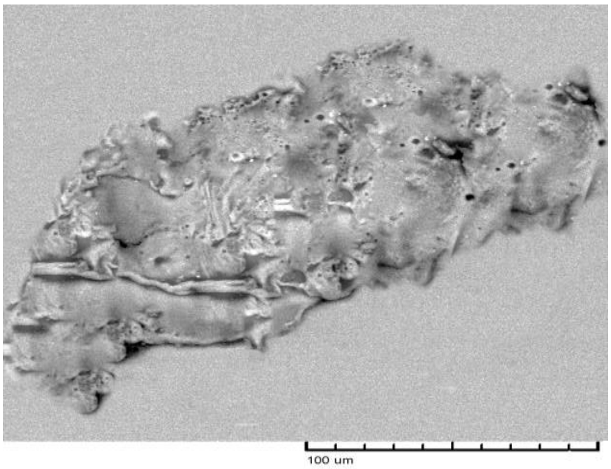

Fig.(6): SEM image of Al on Si substrate at 10 J/cm^2.

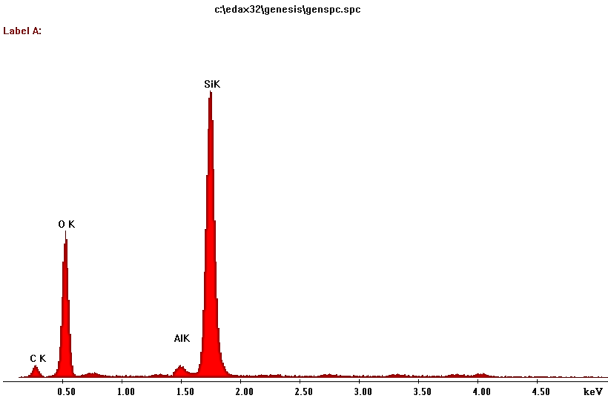

Fig.(7): EDAX spectrum of the deposition of Al thin film on Si substrate.

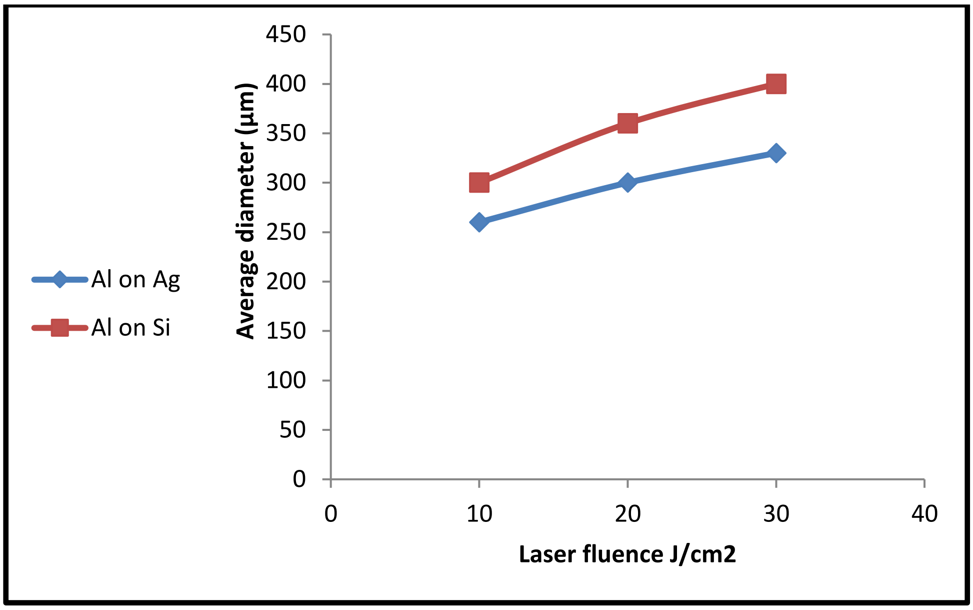

Fig.(8): Diameter of the deposited dots plotted as a function of the laser fluence for Al on Ag and Si substrates.

Conclusion

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 or semiconductors, these results seems to be encouraging when using LIFT technique as a possible tool in industry application.

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الخلاصة

في هذا العمل تم تحضير ودراسة خصائص الألمنيومِ بطريقة الانتقال المحتث المباشر بالليزر. تم تحضير اغشية الالمنيوم بطريقة التبخير الحراري كأغشية واهبة. 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 532 نانومتر و تكرارية 1-6 هرتز وآمد نبضة 10 نانوثانية). حجم الغشاء المرسب على القاعدة المستلمة, طوبوغرافية السطح, وقوة الالتصاق بين الغشاء والقاعدة المستلمة تم دراستها كدالة لكثافة طاقة الليزر المستخدم.