The Basic Concept and Application Status of Laser Induced Forward Transfer

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Abstract. Laser Induced Forward Transfer (LIFT) is a new type of transfer method. It uses high-energy laser as an energy source to irradiate solid or liquid materials, allowing them to be emitted onto the receiving substrate under the force of steam to achieve the transfer of material. Nowadays, although most of the work on LIFT is still in the laboratory stage, compared to the traditional process of LIFT, its nozzle free characteristics, pixel-based transfer method, make it have high production efficiency, universality of materials, and compatibility with Computer numerical control (CNC) machine tools. In this review, the fundamental principle of LIFT is introduced and the great potential of LIFT in many fields is presented and analyzed, including Three-dimensional (3D) bioprinting, industrial manufacturing, energy storage material manufacturing, new-type energy and so on. The conclusion is that if the application of LIFT in the manufacturing field can be achieved, the efficiency and flexibility of modern digital production will be greatly improved. The LIFT method has great development prospects in the manufacturing field.

Keywords: Laser induced forward transfer, High-energy laser, Application, Manufacture.

1. Introduction

The origin of 3D printing can be traced back to the 1980s. In 1986, the first commercial 3D printer called SLA-1 was invented by Charles' Chuck 'Hull, marking the beginning of 40 years of vigorous development for 3D printing [1]. Admittedly, 3D printing plays an increasingly important role in small-scale manufacturing nowadays. However, in practical applications, the popularity of traditional 3D printing is limited by various factors such as printing materials, printing size, and production efficiency [2]. New 3D printing methods are constantly being developed to improve these issues.

This article will focus on introducing a 3D printing technology named laser induced forward transfer (LIFT), which is different from traditional 3D printing technology. Using high-energy lasers as transfer energy, LIFT can change the effect of transfer by changing the laser parameters. As this technology does not have nozzles, it eliminates restrictions on material types. LIFT can also transfer solid or liquid materials in similar principles and some methods can be used to protect these materials during the transfer process. The transfer of materials has high freedom. Meanwhile, the pixel-based transfer method makes it highly suitable for CNC machine tools and is expected to be integrated with other transfer methods. In this way, LIFT has high production efficiency and processing accuracy. Due to the above advantages, although LIFT is still in the early research stage, it has been proven feasible in multiple fields, including 3D bioprinting, industrial manufacturing, manufacture of materials for power storage, etc., and has good development prospects.

2. Basic Theory

2.1. Principle

In LIFT, high-energy laser is used to irradiate a transparent carrier substrate coated with transfer materials, when the energy absorbed by the material layer reaches the corresponding threshold, transfer materials will detach from the carrier substrate at a higher speed and emit towards the receiving substrate. By adjusting the size of the light spot, the resolution of the transfer material can be easily changed. By controlling the frequency and scanning speed of the laser, the transfer

efficiency will be controlled, Thus, LIFT can adapt to different production needs. The main structure of LIFT is shown in figure 1 [2].

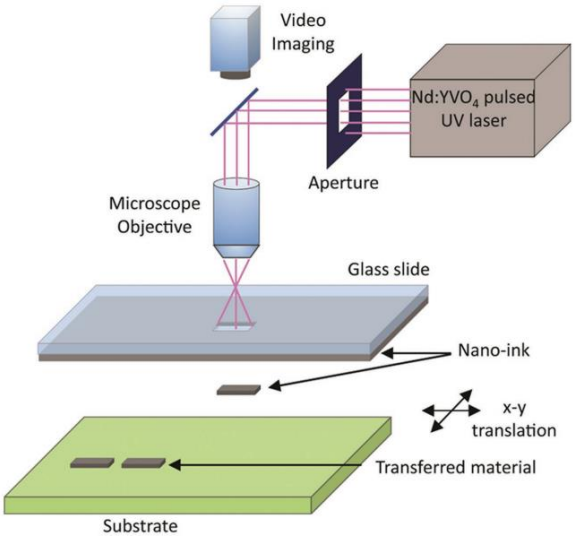


Figure 1. The main structure of LIFT [2]

LIFT is also suitable for different transfer materials. The original LIFT method was mostly used for metal material, such as Cu, Au, Al, etc [2]. However, since LIFT is carried out in a vacuum environment, it does not generate the corresponding oxides of the metal material, eliminating the process of impurity removal. Transfer printing of semiconductors, organic compounds, and liquids can also be achieved by LIFT or its derivative methods, which will be discussed in detail in the following text.

2.2. LIFT Form Solid Donor Films

In the transfer printing of metal and some semiconductor materials, the solid donor film irradiated by laser will undergo phase transformation due to the vaporization in high temperature and be pushed away from the carrier substrate under vapor induced pressure. It is worth mentioning that at low laser fluences, molten metal will form droplets, making the size of the transferred metal smaller than the size of the spot, which also makes the printing of nanoparticles possible [3].

For solid materials that need to be kept intact during the transfer process, such as certain single crystals that need to be kept in good condition, sub-threshold laser scanning can be used multiple times while the receiving substrate is preprocessed simultaneously. For some materials with weak absorption capacity or sensitivity to laser, a sacrificial layer of energy absorption can be pre-coated on the donor substrate, commonly known as Dynamic released layer, abbreviated as DRL. It can absorb laser energy, vaporize, and provide thrust while protecting the transfer material. The most used material for DRL is the photo decomposing triazene polymer [1]. TP-DRL can protect the transfer material from laser's damage, but it may cause interference with the transfer material during the transfer process.

2.3. LIFT Form Liquid Donor Films

The transfer process of liquids is similar to that of solids, but the liquid donor film is thicker (1-100μm). When transferring liquid materials, the position irradiated by laser absorbs energy and generates bubbles which expand and collapse to produce a jet, forming droplets for transfer onto the receiving substrate. Compared to other traditional liquid transfer printing technologies, the LIFT method does not require a nozzle, which means it does not have excessive requirements for liquid viscosity and particle size in the suspension liquid, and its transfer speed is also quite competitive. At the same time, biological macromolecules and cells are also very suitable for LIFT transfer in the liquid phase which can provide good protection for these mutable solid components. The principle of normal LIFT form liquid donor films is shown in figure 2 [2].

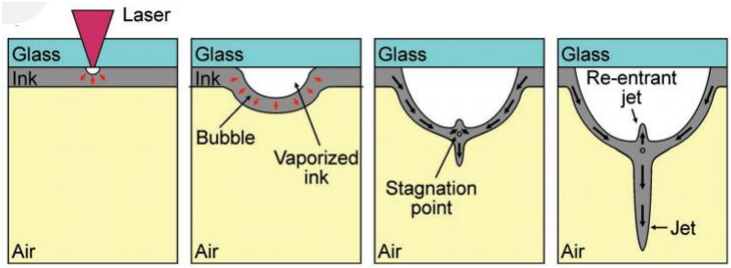


Figure 2. The principle of normal LIFT form liquid donor films [2]

Dynamic released layer can also be applied to liquids with poor laser absorption capacity. But considering the possibility of the damage from vapor to the transfer material, Blister Acted LIFT has been proposed as an improvement method. BA LIFT uses a thicker dynamic released layer, only shallow layers of DRL will be vaporized to provide driven force while deeper layers of DRL serve as protective layers to protect the transfer material. The comparison of normal liquid LIFT, liquid DRL LIFT and BA LIFT is shown in figure 3 [2].

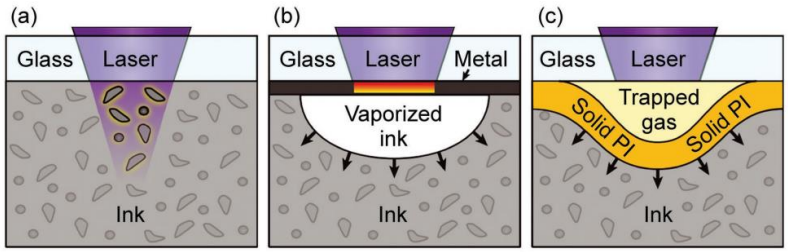


Figure 3. The comparison of normal liquid LIFT (a), liquid DRL LIFT (b) and BA LIFT (c) [2]

3. Application

3.1. LIFT in 3D Bioprinting

3D bioprinting technology is a new technological approach that uses computer 3D models, assemble specialized "bio inks", and ultimately produces artificial organs and biomedical products. It has good development prospects in fields such as healthcare and military defense.

At present, mainstream 3D bioprinting methods include inkjet printing, extrapolation-based bioprinting, and microvalve-based bioprinting, among which the common feature is the presence of a nozzle structure. In the application of these methods, the printing accuracy is contradictory to the activity of biological cells. To achieve high printing accuracy, a smaller nozzle size is required, which can cause certain damage to the activity of biological cells. At the same time, the structure of the nozzle also limits the printing of bio inks with generally high viscosity. But a laser assisted bioprinting technology derived from the traditional LIFT method, named laser-assisted bio-printing, abbreviated as LAB, can solve the above-mentioned problems [4, 5].

This method is similar to the principle of LIFT from liquid donor films using a thinner DRL layer. By irradiating the absorption layer under the transparent glass plate with a laser, a small portion of the biological ink under the absorption layer evaporates and expands, forming a jet emitted onto the receiving substrate.

In early studies, after it was confirmed that the LIFT method is feasible for 3D bioprinting and has advantages over other methods, LIFT was immediately invested in the research of 3D bioprinting. The LIFT method can be mainly applied to two major fields of 3D bioprinting: cell biology studies and tissue engineering. Due to the high resolution brought by the nozzle free structure of LIFT, it can be used to study cell-cell and cell-microenvironment interactions in vitro, as well as to construct embryonic cancer cells and ensure their differentiation capacity in the field of cancer research. On the other hand, thanks to the good localization of LIFT, biological tissues with normal functions can be designed using LIFT method. The LIFT of skin tissue, bone tissue and Nervous tissue is under

study [6]. Due to the lack of nozzle structure, it is difficult for LIFT to achieve flexible switching of multiple printing materials, and it may need to be combined with other 3D bioprinting methods to achieve high-throughput printing.

3.2. LIFT in Industry

Although the current research on the industrial application of LIFT is mainly still at the laboratory level, with the aim of adapting it to industrial applications, the prospects of LIFT in electronics and graphic printing are still very attractive.

Traditional inkjet-based digital circuit printing is only suitable for conductive inks with low viscosity, while LIFT technology can use conductive inks with higher viscosity and a larger particle size range, such as the commonly used ink based on Ag nanoparticles on the market. At the same time, LIFT technology can directly transfer the interconnects of electronic circuits into printed circuits. since the size and shape of the metal deposits transferred by LIFT is very similar to the light spot, the controllability of the LIFT transfer circuit is very strong. After the feasibility of applying LIFT technology in the electronic industry is confirmed, the main research focuses on how to achieve low-cost and efficient commercialization of electronic production through LIFT technology [7, 8].

LIFT in graphic printing is suitable for some special inks which can easily cause nozzle blockage or just can't be handled by traditional printing. For example, some pigments containing large particles can be printed by LIFT. This provides a solution for some special graphic printing industries with relatively small demand but still occupying a certain market. The structure in figure 4 is one of the extensions of laser technology to a four-color roll to roll system made by a team from Daetwyler AG in Switzerland and Inter print GmbH in Germany [2].

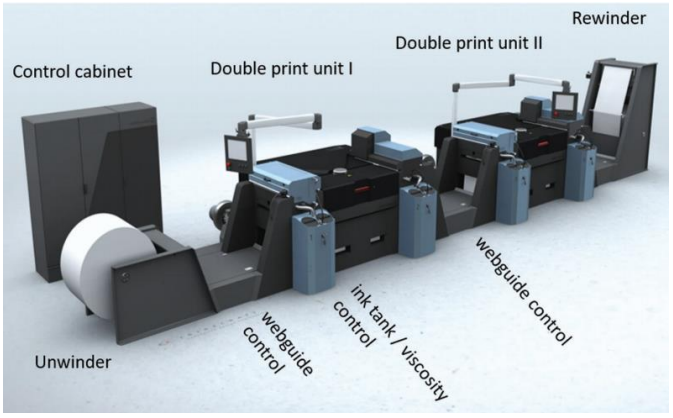


Figure 4. The structure of the four-color roll to roll system involving LIFT [2]

3.3. LIFT of Materials for Power Storage and New-type Energy

In the LIFT transfer of solid materials, the transferred material often exhibits a porous structure, resulting in an increase in its surface area. This means, in electrochemistry the efficiency of electron exchange between the electrode and the electrolyte increases. Therefore, LIFT can be used to manufacture micro energy storage devices [2, 7].

In the photovoltaic industry, compared to traditional screen printing, LIFT technology can effectively avoid silicon wafer breakage and there are no problems such as slurry blockage. Therefore, LIFT has good application prospects in the preparation of solar cell electrodes and is currently a research hotspot in this field. The laser induced front Polarization density device based on the laser induced forward transfer technology is more accurate, faster, and the quality of the grid line is higher than traditional device. The graphics can be customized freely and the structure is relatively simple [9, 10]. The principle of LIFT in solar cell electrode manufacture is shown in figure 5 [11].

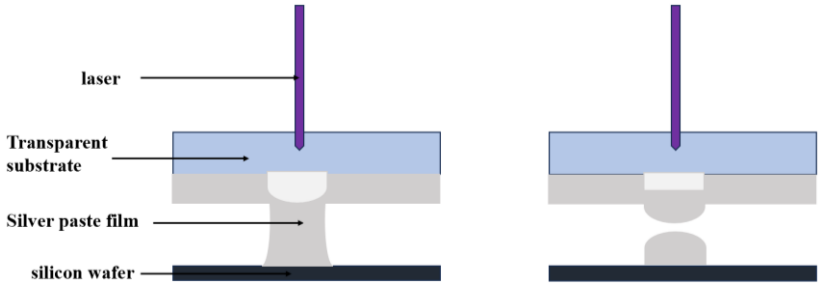


Figure 5. The principle of LIFT in solar cell electrode manufacture [11]

3.4. Advantages of LIFT Compared to Traditional Methods

After the analysis of the practical application of LIFT technology in the previous text, we can easily find that in various fields, there are commonalities in the advantages of LIFT technology compared to traditional technologies.

Firstly, due to the lack of nozzles which is required in traditional transfer printing technology, there are very few restrictions on the materials that can be transferred in LIFT technology. In addition, the usage of sacrificial layers further expands the range of available materials for LIFT, which gives it great material versatility. With the maturity of LIFT technology, it can be used in almost any manufacturing field. Secondly, the LIFT technology is non-contact, so in LIFT there are no problems which is very frequent in traditional contact manufacturing processes such as mechanical wear. Furthermore, in LIFT, the result of transfer can be controlled by controlling the size of the light spot, laser frequency, and scanning speed. In addition, with its pixel-based transfer characteristics, LIFT is very suitable for combining with intelligent CNC machine tools to achieve excellent transfer quality and efficiency [9].

4. Conclusion

As a direct transfer technology, LIFT uses high-energy lasers as its energy source and can flexibly transfer solid or liquid materials. Due to the flexibility of its transfer materials and pixel-based printing methods, the LIFT method is more suitable for the digital development trend of modern manufacturing industry. Due to the complementarity between the advantages of LIFT and traditional methods, it is expected to replace traditional methods in certain fields or integrate with traditional methods to adapt to new production requirements. Due to its versatility, LIFT has shown promising development prospects in various fields.

Although LIFT is still in the early experimental stage and has some issues, such as difficulty in achieving high-throughput transfer, controllability of transfer materials, and manufacturing and maintenance of transfer equipment. These problems are very difficult to solve at present. But in the future, with the breakthroughs in technology, the introduction of new control methods, and the integration with other mature methods, it is believed that these problems can be solved one by one, and the LIFT method will be able to demonstrate its advantages in the field of digital manufacturing.

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