# MICRO-413 (2022) / LIFT: Exercise 3 solutions

1. In order to realize successful printing of materials by Laser-induced forward transfer (LIFT), many parameters (such as laser energy, laser wavelength (λ), laser pulse duration (τ), repetition rate, etc.) need to be carefully chosen. Please answer the following questions.

a) Assuming there are several laser sources (listed in the table below) available for LIFT printing. The wavelength-transmission curves for the donor substrate and the material to be transferred are given in the following plot. Find the suitable laser source(s) for LIFT printing and explain why.

**Table 1. Common Lasers and Their Wavelengths**

| LASER TYPE | WAVELENGTH (nm) |
|---|---|
| ArF | 193 |
| KrF | 248 |
| XeCl | 308 |
| Nd:YAG | 355 |
| Ti:Sapphire | 690 |

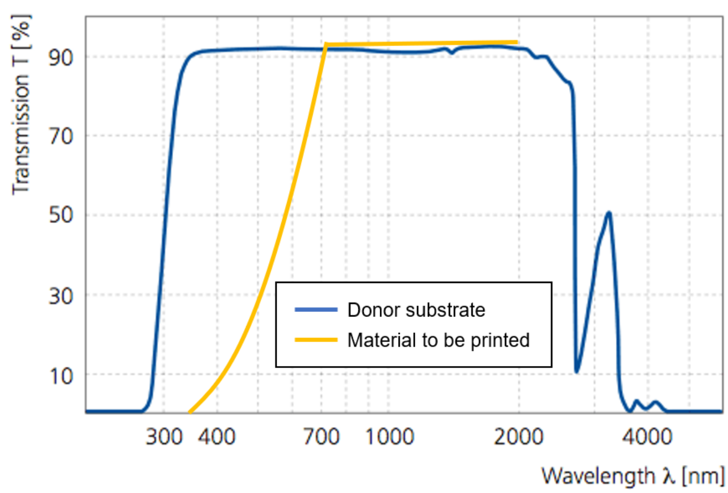


**Figure 1. Wavelength-transmission curves of the two materials**

b) Imagine that we have a laser source with a laser energy of 1 μJ, τ of 1 ns and a repetition rate of 300 Hz. If we operate the laser at the repetition of 300 Hz for 1 s, calculate the peak power and the average power of the laser.

c) Assume the laser can print materials with a pixel resolution of 20 μm (which means the size of the printed material on the receiver substrate is 20 μm in diameter). The stage of the receiver can move up to 100 mm/s. If the repetition rate of the laser is 300 Hz, what is the maximum moving speed of the stage to guarantee the continuity of the printed structure? If we want to move the stage at the maximum speed, what is the minimum repetition rate?

**Answers:**

a) From the list and the figure, we should choose the Nd:YAG laser with the wavelength of 355 nm.

The reason is that the donor substrate is transparent when the wavelength is larger than 350 nm (~92 % transmission). This means that the laser will not be absorbed by the donor substrate, and we can preclude the ArF, KrF and XeCl lasers.

When we have a look at the Ti:Sapphire laser (690 nm). Although it is transparent for the donor substrate, it is also transparent for the material to be printed. This means that there will be no laser-material interaction, so that the material cannot be printed by this laser.

In this case, the Nd:YAG laser is the only choice because it is transparent for the donor substrate and opaque for the material to be printed.

b) $P_{peak}$ = Laser energy/$\tau$ = 1 μJ/1 ns = $10^3$ W

$P_{average}$ = Laser energy × repetition rate/1 s = 1 μJ × 300 Hz/1 s = $3 \times 10^{-4}$ W

c) If the repetition rate is 300 Hz, then for two consecutive pulses the time interval is 1/300 s. This means within this interval, the stage should not move more than 20 µm to guarantee that the printed material form continuous structure. So, the moving speed of the stage is no larger than 20 µm/ (1/300 s) = 6 mm/s.

If the stage moves at maximum speed (100 mm/s) and the pixel resolution is unchanged (20 µm), then the repetition rate should be no smaller than (100 mm/s)/20 µm =5 kHz.

2. Since its debut in 1986, various complementary LIFT techniques have been proposed and developed to overcome its inherent problems. Here I list some abbreviations for the LIFT variations (**LIBT, DRL-LIFT, MAPLE-DW and LITI**). Please make drawings and explain their working principles.

**Answers:**

**Laser-Induced Backward Transfer (LIBT)**

LIBT has a similar transfer process like LIFT, except that the donor and the receiver are placed upside down. The receiver also needs to be transparent to the laser irradiation to allow the laser pass through, as shown in the scheme Figure 2B.

**Dynamic Release Layer LIFT (DRL-LIFT)**

In DRL-LIFT, there is a sacrificial layer deposited between the carrier and the donor layer. When the incident laser irradiates on the sacrificial layer, the laser energy will be fully absorbed by this layer, leading to the complete vaporization of this layer. As a result, the donor film stays intact and the pressure created by the vapor bubble leads to the transfer of the donor film (Figure 2C). DRL-LIFT is advantageous over the traditional LIFT because it can transfer more delicate materials which are heat-sensitive and prone to be damaged by the laser. It is noteworthy that the residues of the DRL can contaminate the donor film if not decomposed completely, so the compatibility of this technique with some materials should be taken into account during the transfer.

**Matrix-Assisted Pulsed Laser Evaporation-Direct Write (MAPLE-DW)**

MAPLE-DW technique is a combination of MAPLE and LIFT. In this technique (Figure 2D), the donor material is embedded into a solvent matrix material with a low evaporation point (much lower than the melting point of the donor material). Upon absorbing the laser beam, the matrix decomposes into volatile by products and then propels the donor material towards the receiver. This method features a pyrolytic process only for the matrix material, keeping the donor uninfluenced by the laser. Due to its flexibility, MAPLE-DW has been employed to print a lot of materials, including metals, organics and cells.

**Laser Induced Thermal Imaging (LITI)**

LITI, with the same working principle as DRL-LIFT, is mainly designed for printing and patterning conductive polymers. A slight difference between these two methods is that the intermediate layer in LITI, referred to as the Light to Heat Conversion Layer (LTHC), is a metallic layer (Figure 2E). Such design guarantees the LTHC layer will not be ablated; instead, heat converted from the absorbed laser will decrease the adhesion between the donor and the LTHC and decomposes surrounding organics into gaseous products. This decomposition and ensuing expansion propel the polymer layer towards the receiver.

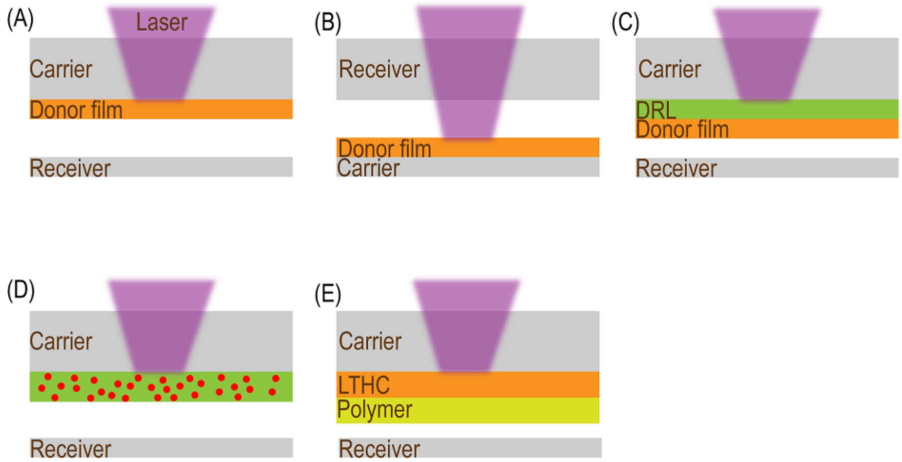


**Figure 2. Sketches of the variations of the LIFT process. (A) to (E) represents LIFT, LIBT, DRL-LIFT, MA-PLE-DW and LITI, respectively.**