Droplet generation in a microfluidic device using a T-junction geometry

Microfluidics is a science that studies how to manipulate small amounts of liquids (between pL and nL) using micrometer size channels (between 10 - 500 µm).

Due to the low Reynolds number (Re<1), microfluidic channels are characterized by laminar flow, making microfluidics suitable to the production of controlled emulsions of two or more immiscible fluid phases. In other words, it is possible to generate droplets of one phase (dispersed phase) into the other (continuous phase) by using specific geometries. This generation typically results highly monodispersed (variation less than 2% in droplet size distribution) even at very high frequency (up to kHz in some cases). Therefore, droplet microfluidics allows the manipulation of liquid volumes smaller than monophasic microfluidics and the creation of independent compartments. Actually, every droplet can be considered as a single and isolated reservoir. For these reasons, this technology is currently spreading in many biomedical applications, mainly related to single-cell encapsulation and analysis.

One of the most common geometries used for droplets generation is the T-junction (see Figure 1a), in which the droplet formation is regulated by two forces: i) the shear-stress applied from the continuous phase to the interface of the dispersed phase and ii) the capillary pressure which goes against its deformation. Therefore, droplets size and frequency depend on these two forces which can be controlled via the channel geometry, the liquid properties (e.g.: viscosity, surface tension) and the applied flows of the two phases.

In this experiment, a T-junction microfluidic device is used to generate water-droplets in an oil phase, which are flown along a capillary. Size and frequency of production are controlled by tuning the flow rates of the continuous and dispersed phases by two syringe pumps (see Figure 1b). Aim of this experiment is to evaluate several parameters related to the droplet generation (like its stability over time, droplet size monodispersion, generation frequency, etc.), by tuning the flow rates applied to the water and oil phases. The measurement of these parameters is carried out using photocells tracking the droplet passage in the capillary.
The work activity can be divided in two parts: 1) realization of the optical detector and relative capillary holders, 2) characterization of a microfluidic T-junction droplet generator.

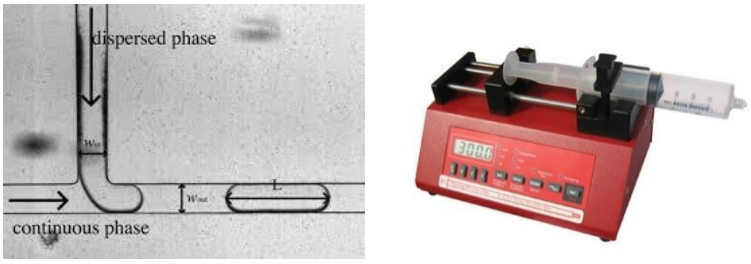

Figure 1: Left: microfluidic T-junction. Right: syringe pump

1st part – Optical detector

The optical detector (see Figure 2) consists of pairs of optical fibers placed in correspondence of a capillary: one illuminates the capillary, while the other one collects the light transmitted through the capillary. In this way, the droplet acts as a dark object which partially absorbs the LED light. Therefore, the two optical fibers must be coupled with a LED and a photodiode, respectively, which are driven by two independent electric circuits (see below).

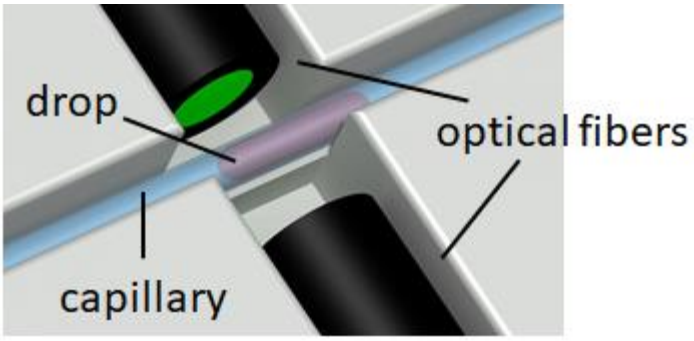

Figure 2: Scheme of the optical fibers placed in correspondence of the capillary.

LED CIRCUIT

Figure 3 describes the circuit for the LED supply. The LED current can be varied using the variable resistor P0 (trimmer). Choose P0 and the fixed resistor R values according to the maximum current passing though the LED (see datasheet).

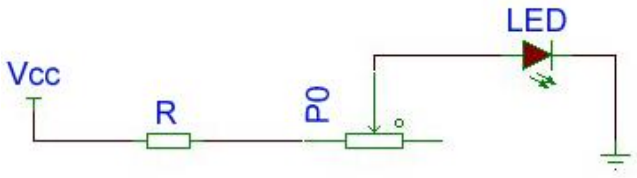

Figure 3: Scheme of the LED circuit (Vcc=5V)

PHOTODIODE CIRCUIT

The photodiode is inserted in a feedback circuit with a gain on the output signal of about 5 and the possibility to vary the output offset.

Circuit realization steps

1) assemble only the part of the circuit reported in Figure 4a. Chose R1 in order to obtain a gain factor between 5 and 6. After **shielding** the photodiode (blocking the ambient light), measure the output gain, taking into account that the operational amplifier present in the photodiode has a voltage source of 7.5mV connected at the not-inverting input (see photodiode datasheet OPT101 by Texas Instruments).

2) assemble the second part of the circuit as shown in Figure 4b and apply at V2 a negative voltage of "-5V". Working with the **shielded** photodiode, find out the best values of the resistance R3 and the variable resistance P (trimmer) in order to be able to sweep the output signal (pin 5) throughout the whole voltage supply range (from 0 to 5V).

3) set the supply "V2" at positive voltage (5V) and use the standard (not-shielded) photodiode to verify the correct mode of operation of the circuit. In detail, verify that it is possible to set to zero the output signal due to the residual ambient light by acting on the trimmer.

ATTENTION: the photodiode is very sensitive and can saturate once exposed to the ambient light. Therefore, this last regulation must be done in the final working conditions, e.g. with the photodiode embedded in the 3D printed part and optical fiber connected (see 3D printer paragraph).

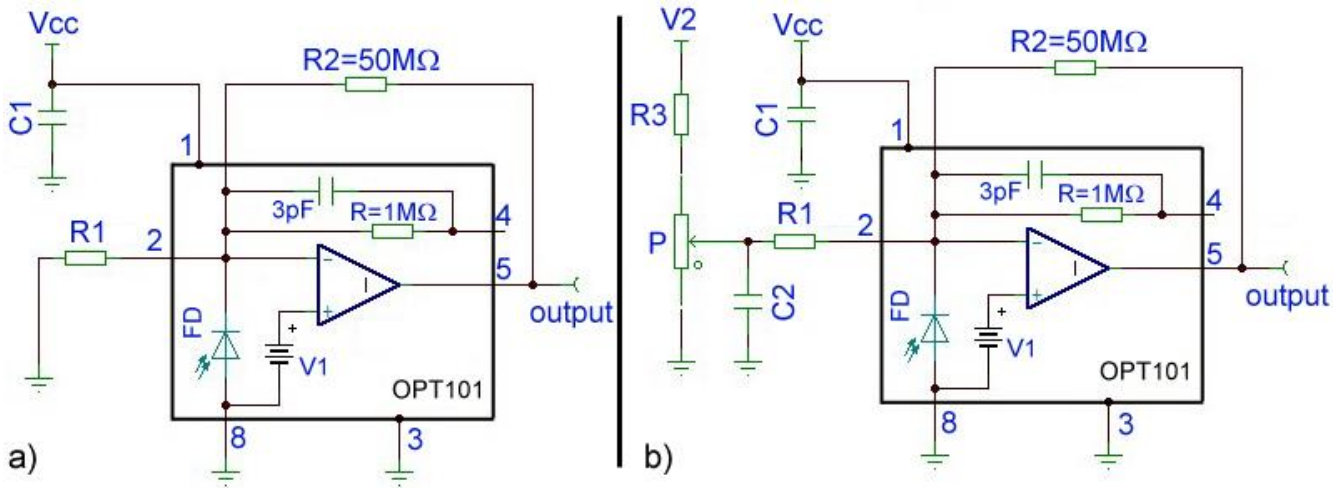

Figure 4: : scheme of the photodiode circuit without (a) and with (b) the part regarding the offset regulation (Vcc=5; V1=-5 o +5V). The central box (continuous bold line) reports the block diagram of the photodiode (see datasheet). The resistance of 50MΩ corresponds to the highest value that is suggested in the datasheet. See "advice 4" for the capacitor values.

3D PRINTING OF THE FIBERS HOLDER

Prepare with the 3D printer two types of holders that allow coupling of the two optical fibers with the LED and the photo-detector (Figures 5 and 6, respectively). The latter holder must also guarantee the shielding of the ambient light. Produce also a third part that allows to fix the optical fibers close to the capillary in which droplets will pass thought (see scheme in Figure 2).
For the 3D printing, an **".stl"** file must be produced. For the generation of this file type, any personal software can be used; differently, it is possible to free download "FUSION 360" (student license) from the Autodesk website, that allows 3D drawing and ".stl" conversion (https://www.autodesk.com/products/fusion-360/students-teachers-educators).
Examples of 3D printed parts produced are provided.

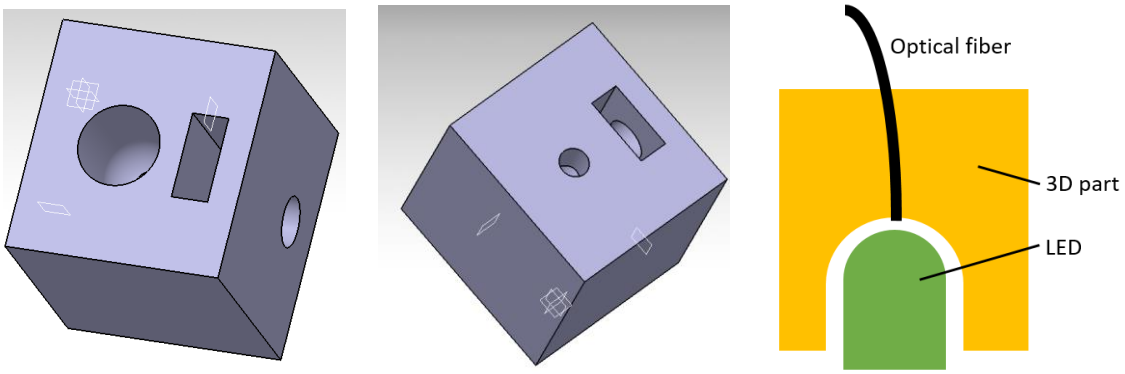

Figure 5: example of the structure to couple the LED with the optical fiber.

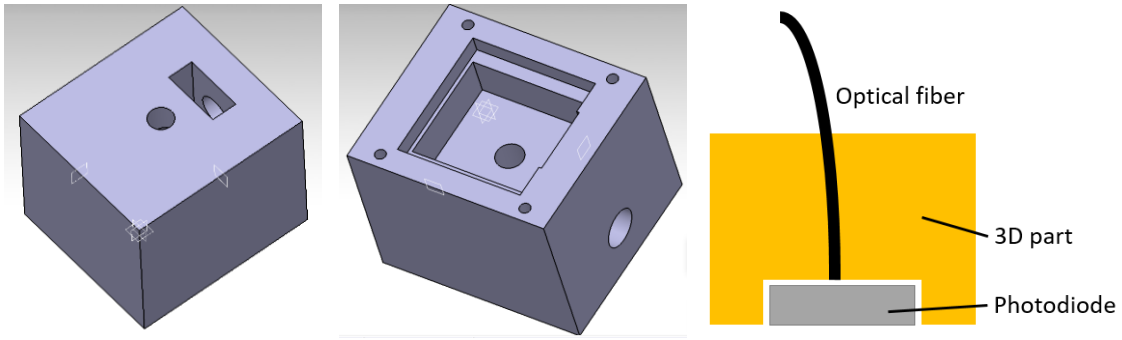

Figure 6: example of the structure to couple the photodiode and the optical fiber

ADVICE (1st PART)

1) Verify that the photodiode is well shielded from the ambient light during the tests to characterize the relative circuit.

2) Regarding the photodiode circuit (Figure 4b), use resistance (R3) and variable resistance (P) between 1÷20kΩ.

3) The capacitors in the circuit of Figure 4 act to filter the possible noise coming from the supply voltage. Suggested values are between 100÷1000nF.

2nd part - Droplet generation and quantification

MICROFLUIDIC DEVICE AND LIQUIDS USED

The microfluidic device is made by soft-lithography using polydimethylsiloxane (or PDMS), which is an elastomeric, transparent and hydrophobic polymer. The geometrical features of the T-junction are reported in Figure 7. The capillary used for the droplet transport outside the device is a PTFE tube has a nominal outer (inner) diameter of 0.6mm (0.3mm).
The liquids that will be used during the experiments are:

- Continuous phase: mineral oil light with 2%(w/v) of SPAN80. The latter is a surfactant that is added to reduce the interfacial tension between oil and water to favor the droplet formation.
- Dispersed phase: distilled water mixed with red ink to help the droplet identification.

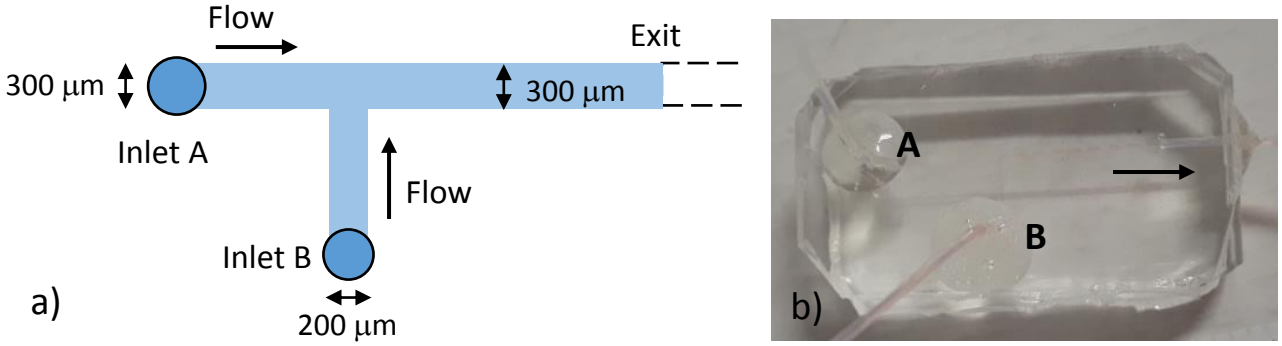

Figure 7: (a) Scheme of the microfluidic circuit. A and B are the inlets for the continuous and dispersed phases, respectively. Channels have a thickness of 200µm. (b) Picture of the device with indication of the inlets A and B reported in the scheme.

Installation and connection steps

1) Fill the syringes with the two liquids and mount them in the respective pumps for controlling the flow rates. Try to avoid air bubbles in the syringes.
2) Connect the tubes from the microfluidic device to the respective syringes.
3) Start with only the syringe A (continuous phase) in order to completely fill all the channels with the oil phase.
4) Then, start the syringe B (dispersed phase) and verify the droplet formation at the T-junction.
5) PTFE tube transports the droplets away from the PDMS device. The passage of the droplets can be detected by using the photocells.
6) Tuning the flow rates of both phases in order to change the production rate and the droplet size.

ADVICE (2nd PART)

1) To avoid damaging the microfluidic device, use flowrates lower than 80μL/min.

2) Air bubbles in the fluidic circuit act as dumpers reducing the response time of the liquid when the flowrate is changed. Therefore, it is recommended to wait that the droplet generation is stable after having changed the flow values.

3) Place small pieces of paper in correspondence of the tube connections and below the microfluidic device, in order to verify immediately eventual leakage of liquids.