A Compact, 3D printable Purge System for Terahertz Spectroscopy

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We present the design of a compact purge system designed for the TeraSmart terahertz spectrometer offered by Menlo Systems, but compatible with other spectrometers based on fiber coupled photoconductive antennas. While connected to the nitrogen (or dry air) source, the system effectively deals with water vapor absorption that is a well-known issue in terahertz spectroscopy limiting a signal-to-noise ratio. The system was designed for the lens-based version of the TeraSmart spectrometer arranged in a linear configuration for transmission measurements schematically shown in Fig. 1. However, the underlying idea can also be adapted to a reflection configuration or a mirror-based spectrometer with off-axis parabolic mirrors mounted in a cage system.

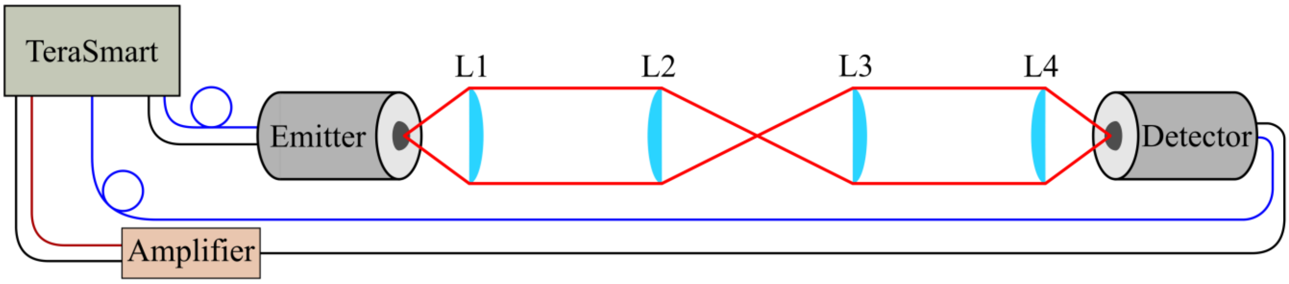

Fig. 1 Schematic drawing of TeraSmart spectrometer in the linear configuration for transmission measurements.

The purge system consists of a handful of components designed for 3D printing using a conventional filament-based printer and a few standard opto-mechanical parts obtained from Thorlabs. The overview of the complete system is shown in Fig. 2. Instead of building a large single chamber enclosing all optical components of the spectrometer, which is a usual approach, we have designed a separate enclosure for each pair of adjacent components. Due to the small total volume of the system, this approach allows for extremely fast purging. This in turn saves time, especially when multiple samples have to be measured.

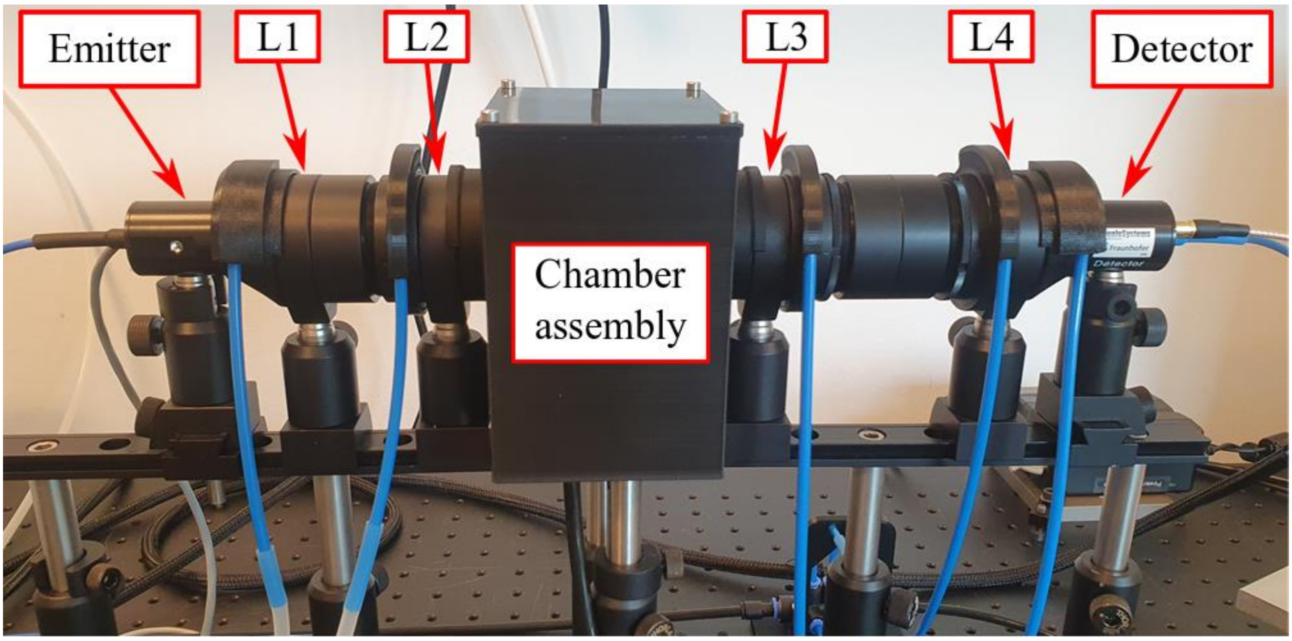

Fig. 2 An overview of the purging system.

Mechanical design

The main part of the system is a chamber assembly that consist of **the chamber** (main chamber.STL), **the lid** (lid.STL) and two **tube**s (tube.STL) as shown in Fig. 3. It acts as a sample compartment and provides enclosure between two central lenses (L2 and L3 in Fig. 1). Its internal dimensions of 69 mm x 94 mm x 100 mm allow the measurements of various types of samples. Four holes at the top of **the chamber** are designed to be tapped for M3 screws to close **the chamber** with **the lid**. Alternatively, magnets can be mounted in the holes allowing for faster access to the sample. By sliding the **tube**s along the openings of **the chamber**, they can be adjusted to a specific lens spacing. The fit between the **tube**s and **the chamber** openings is rather tight; therefore, it may be necessary to polish the holes with a sandpaper. The overhang of the tube should be placed on top of the lens mount. The inside diameter of the tubes is bigger than the clearance of the lens mounts therefore; it is not possible to damage the optics with the **tube**s.

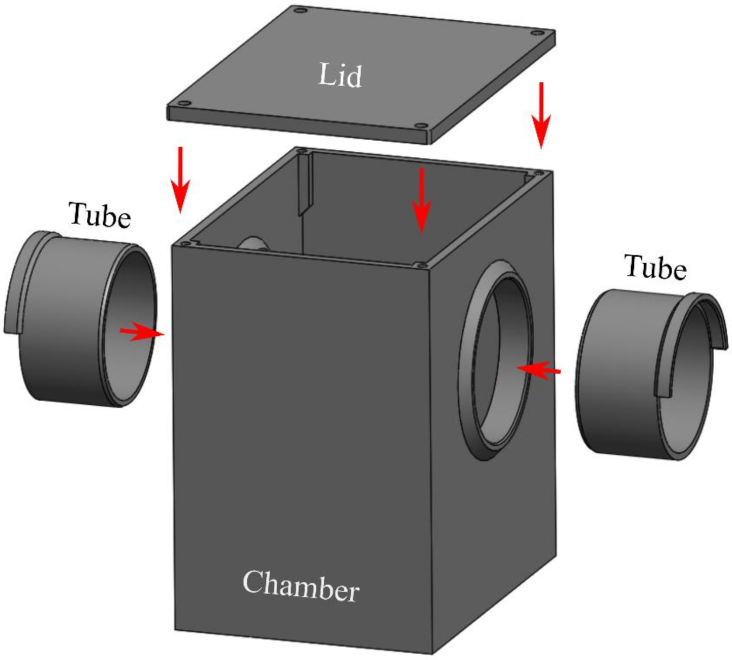

Fig. 3 Exploded view of the chamber assembly.

On the bottom of the chamber, there is a bunch of utility holes (Fig. 4). The through hole in the center is used to fix the sample holder inside **the chamber**. It can be tapped with an M6 thread and used to attach a standard post holder e.g. PH30/M by Thorlabs. The through hole with ⌀6 mm is used as a nitrogen inlet. Additionally, there are nine blind holes arranged around the perimeter of the square. The holes can be tapped with M4 thread and can be used to attach **the chamber** to the optical table. The chosen hole-arrangement was made to fit the KB75/M kinetic base (Thorlabs), which can be used to mount **the chamber** in case it need to be repeatedly inserted and removed, e.g. in order to replace it with other equipment.

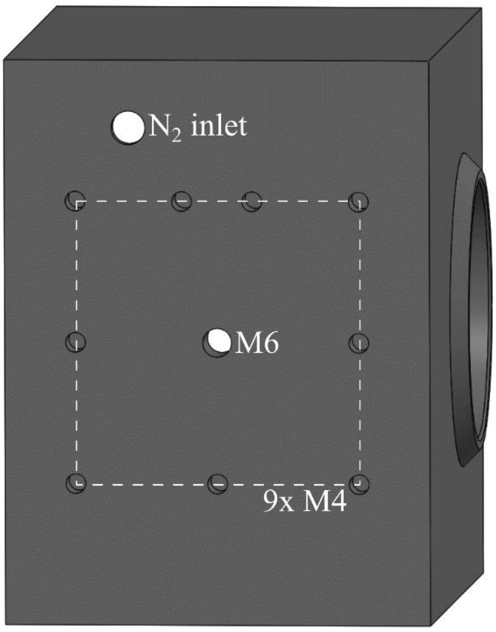

Fig. 4 Bottom view of the main chamber.

To enclose the space between the L3 and L4 lenses (Fig. 1), we used two stackable lens tubes (SM1.5L05, Thorlabs) and two adjustable lens tubes (SM1.5V05, Thorlabs) arranged in the symmetrical setup (Fig. 5). Noteworthy, these components come in different lengths that should be selected according to system requirements. A lens tube is attached to each lens mount. By positioning the adjustable lens tubes along the lens tubes, it is possible to close and open the space between the lenses. To create the tight enclosure, it is important that the lenses are coaxial. This should be ensured during alignment process. By opening the gap between a pair of adjustable lens tubes (e.g. between L3 and L4 in the center of Fig. 5), one can still insert a sample into the collimated part of the THz beam if necessary.

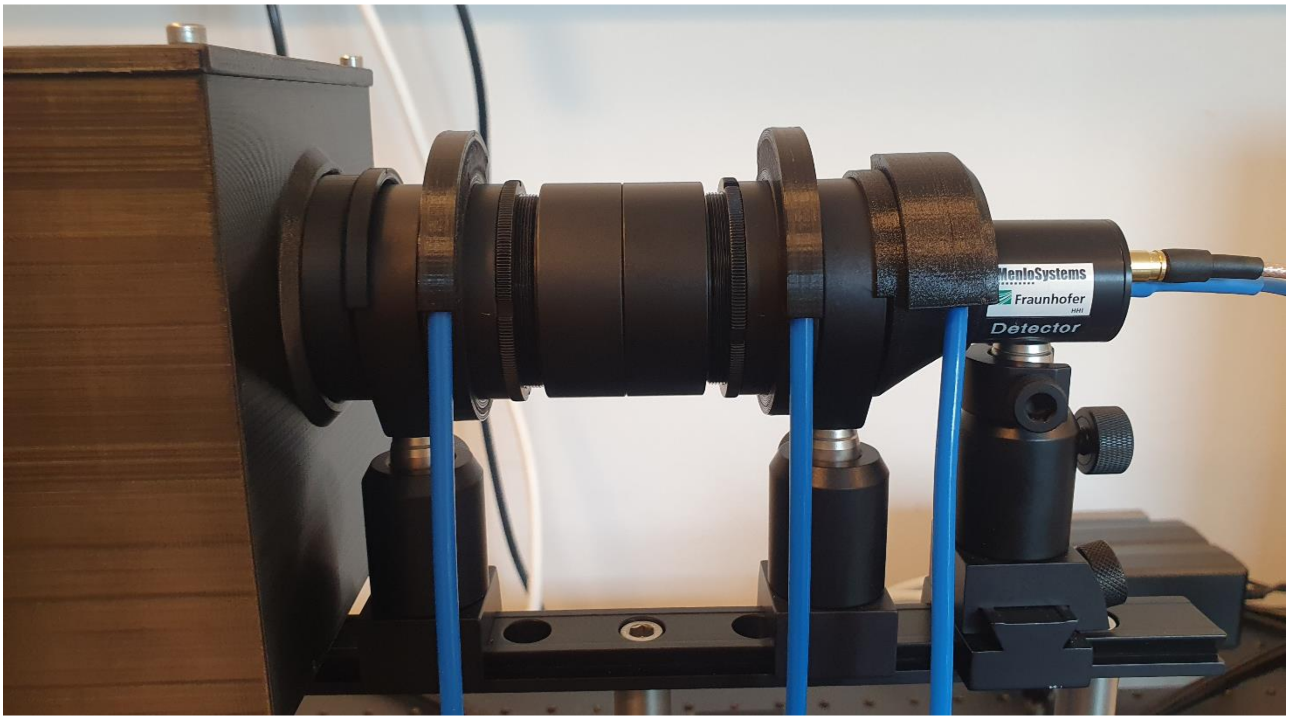

Fig. 5 A close-up on enclosure between L3 and L4 lenses.

In order to supply nitrogen inside the lens tubes system, we 3D-printed a push-on **collar** (collar.STL) for each lens tube (Fig. 6); one mounted on each lens mount. The fit between the **collar** and the lens tube is tight; therefore, polishing the interior of the **collar** is required. From our experience, it is not necessary to further seal the connection. The inlet of the **collar** is designed for 4 mm tubing. Here, the fit is rather loose so that detaching the tube would not affect the alignment of the lens. The groove inside the collar distributes nitrogen around lens tube circumference. To let nitrogen into the lens tube we drilled three ⌀2.5 mm holes evenly spaced around its circumference at the distance of around 4.3 mm from the external thread. The distance between the lenses should be adjusted so the spacing between the two adjustable lens tubes in the fully opened position (without retaining rings) is 10-14 mm. This ensures that the adjustable lens tubes would not obscure the holes drilled in lens tubes. Furthermore, it ensures easy assembly of the setup and allows installing an additional sample holder for measurements with a collimated THz beam as mentioned above (the sample can also be clamped directly with the two adjustable lens tubes). It is worth noting that the spacing between the two adjustable lens tubes is the only nitrogen outlet therefore, it should not be tightened too much.

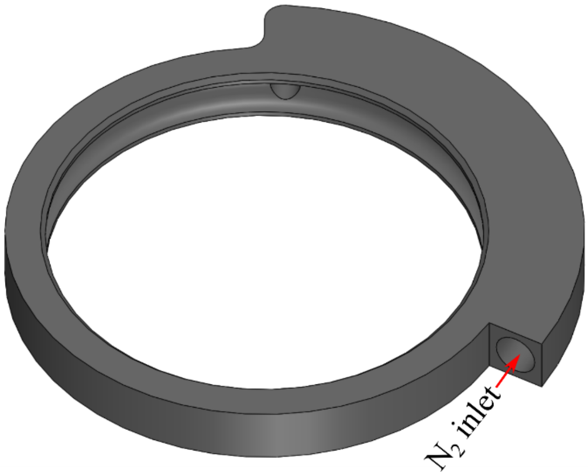

Fig. 6 The model of a collar used to supply the nitrogen into the compartment created by lens tube system.

For closing the space between the L1 and L2 lenses, we used a similar concept as for the L3 and L4 lenses. However, instead of using a symmetrical setup, we used only one standard lens tube and one adjustable lens tube that were stacked and attached to the L2 lens mount as shown in Fig. 7. To close the space between lenses, the adjustable lens has to push against the L1 lens mount. Therefore, coaxial alignment of the lenses is important in this case as well, as for the lenses L3 and L4. The reason for not using a symmetrical lens tube setup in this part of the system is that extending the THz path too much would move the signal out of (or too close to the end) the scanning range of the THz spectrometer delay stage.

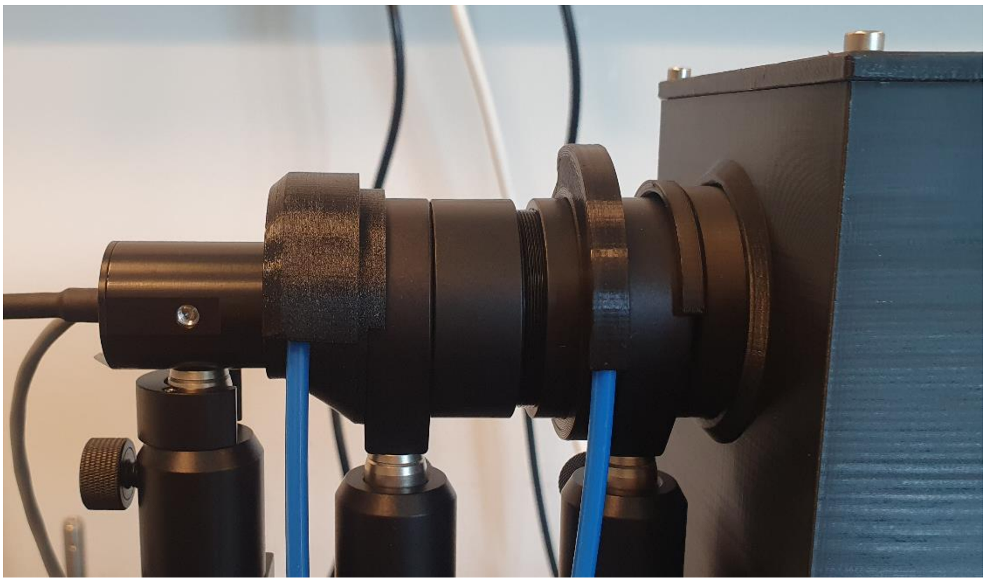

Fig. 7 A close-up on enclosure between L1 and L2 lenses.

3D printed **conical collars** were used as an enclosure between THz antennas (emitter and detector) and adjacent lenses (L1 and L4, respectively). The **Conical collar** comes in two variants left (conical collar left.STL) and right (conical collar right.STL) shown in Fig. 8. This allows arranging the inlets on one side of the system as shown in Fig. 2. Unlike the other 3D printed parts used in the system, which were printed from PLA, the **conical collar**s were printed from flexible TPU. More information can be found in the 3D printing section. Since the lenses have to be coaxial to keep the lens tube enclosure tight, the THz signal is optimized by adjusting the antennas position. The flexibility of the **conical collar** allows it to compensate for small antenna displacements, while keeping the **conical collar** in close contact with the lens mount. Furthermore, the fit between the antenna and the conical collar is very tight to allow the **conical collar**s to hold firmly onto the antennas.

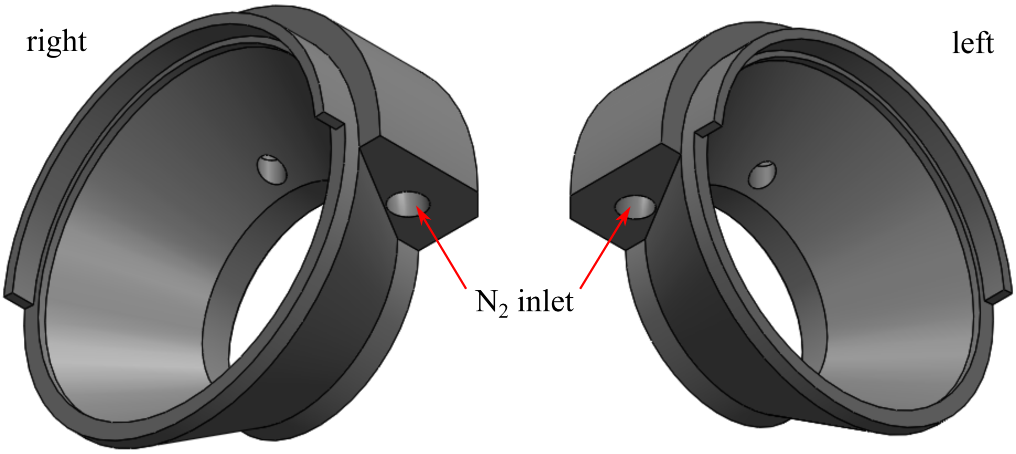

Fig. 8 Models of conical collars used to enclose the space between the antennas and adjacent lenses

Nitrogen supply

Nitrogen was supplied to the system via ⌀6 mm tubing. If nitrogen is not available, dry air can be used instead. A *flowmeter* (Variable Area Flow Meter 25102A15BVBN, Brooks Instrument) with operating range 1-10 l/min controls the flow of nitrogen. To supply the nitrogen into the separate compartments we divided the flow using a manifold tube-to-tube fitting (KM11-04-08-6, SMC). The *manifold fitting* has two ports for ⌀8 mm tubes and ports six ⌀4 mm tubes. The larger ports (⌀8 mm) were adapted for ⌀6 mm tubing using tube-to-tube adaptors (3166 06 08, Legris). One of them was connected with the output of the flowmeter. Since the chamber assembly volume is significantly larger than the volume of other compartments, we used the other larger port to purge it with ⌀6 mm tube. For purging the other compartments, we used smaller manifold ports. To this end, we connected the manifold with three **collar**s and two **conical collar**s with ⌀4 mm tubes. The remaining sixth port was closed using a *blanking plug* (3126 04 00, Legris).

To organize the setup better, we designed and 3D printed two additional components. However, these components are not required for the correct operation of the system. *Flowmeter holder* (flowmeter holder.STL) allows attaching the *flowmeter* to the optical table in the vertical position. *Manifold fitting stand* (manifold fitting stand.STL) allows mounting the *manifold fitting* to the optical table and helps organizing ⌀4 mm tubes attached to *manifold*.

System performance

We have tested the performance of our system using DHT22 humidity sensor controlled by Arduino. The tests were performed in two locations: inside the main chamber and inside the compartment between the L3 and L4 lenses. These are the largest compartments purged with ⌀6 mm and ⌀4 mm tubing, respectively. Therefore, their performance should be a good indication for the entire system. We purged the system with of nitrogen at a flow of approximately 8 l/min. The temperature in the room was approximately 23 °C and relative humidity was roughly 50%. Table 1 shows the performance of the system (the higher relative humidity value obtained from the two tested locations) for different purge times.

Table 1 Relative humidity inside the system measured for different purge times.

Purge time (min)	Relative humidity
2	10%
5.5	5%
10	3.5%
15	2.7%
20	2.2%

As shown in Table 1, the relative humidity in the system dropped to 10% in just about 2 minutes of purging. After 10 minutes of purging, when the relative humidity was around 3.5%, we measured the THz spectra of the atmospheric water vapor and compared it with the one recorded before purging. As shown in Fig. 9, most of the absorption peaks related to atmospheric water vapor was effectively suppress. Finally, the relative humidity stabilized at approximately 2.2% after 20 minutes of purging. It is worth noting that during the test, the compartments were not completely closed due to the connecting cables. Therefore, we expect the system performance to be better than the test results indicate.

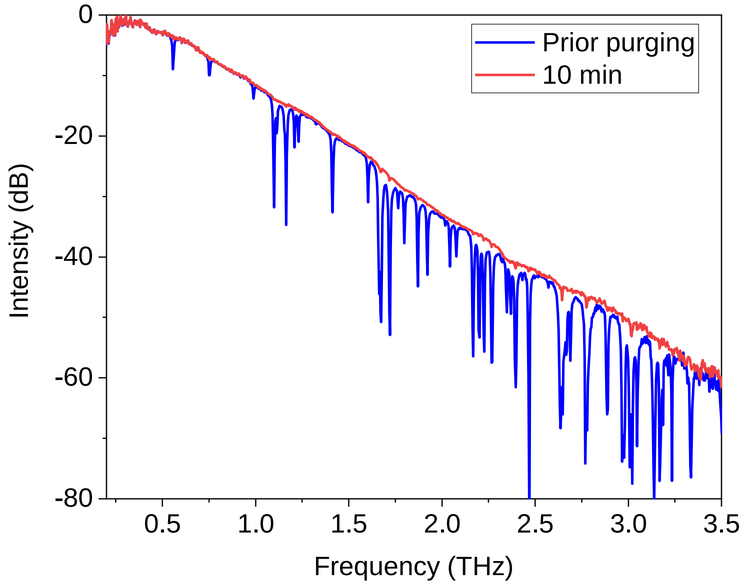

Fig. 9 THz spectra of atmospheric water vapor recorded before purging (blue line) and after 10 minutes of purging (red line).

3D printing

We printed all the components on a Creality CR10 V3 printer. The most relevant printing parameters are listed in the table below:

components	main chamber lid tube collar flowmeter holder manifold fitting stand	conical collar right conical collar left
Filament	PLA PRO by 3DSUPREME	KungFuFlex (TPU85A) by 3DE
nozzle temperature	215 °C	230 °C
bed temperature	55 °C	55 °C
printing speed	55 mm/s	30 mm/s
miscellaneous		no retraction

Contact information

In case of any questions related to the system, please contact us:

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