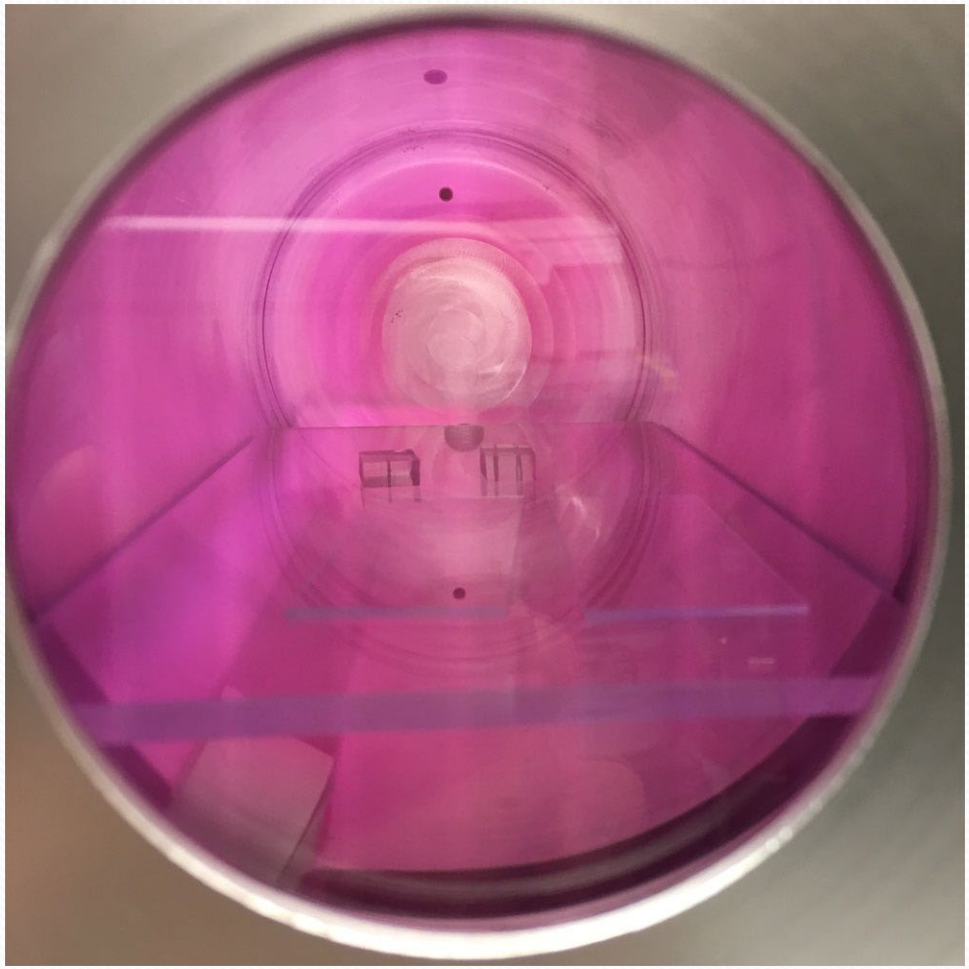
Tergeo Plasma cleaner

Application notes on PDMS bonding with glass and other polymers

Tergeo for PDMS/Glass bonding



Recipe for PDMS bonding:
RF power 15Watt
RF pulse duty ratio: 10% to 20%
Gas: Room air or oxygen (water vapor is optional for more consistent results)
Flow rate: 5-50sccm
Time: 20~40 seconds

PDMS-Glass bonding Results

Bond PDMS/Glass immediately, No need to cure the device in an oven

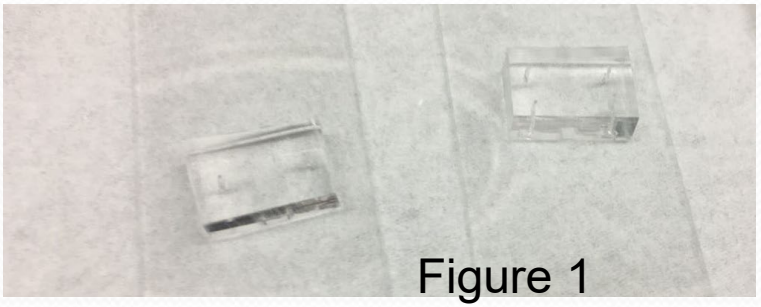


Figure 1

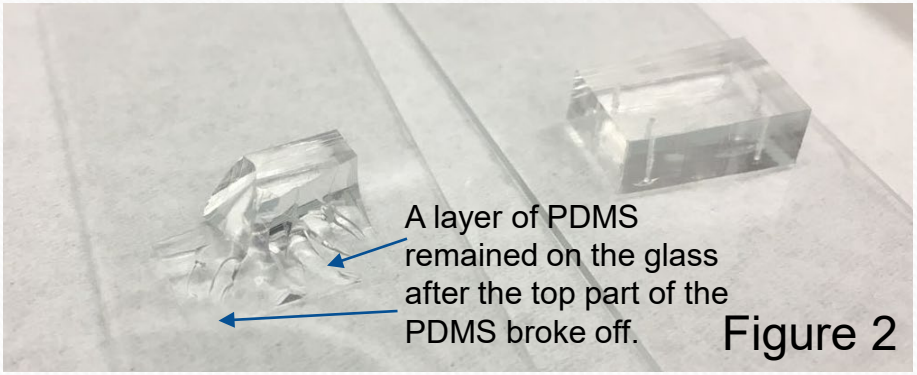


Figure 2

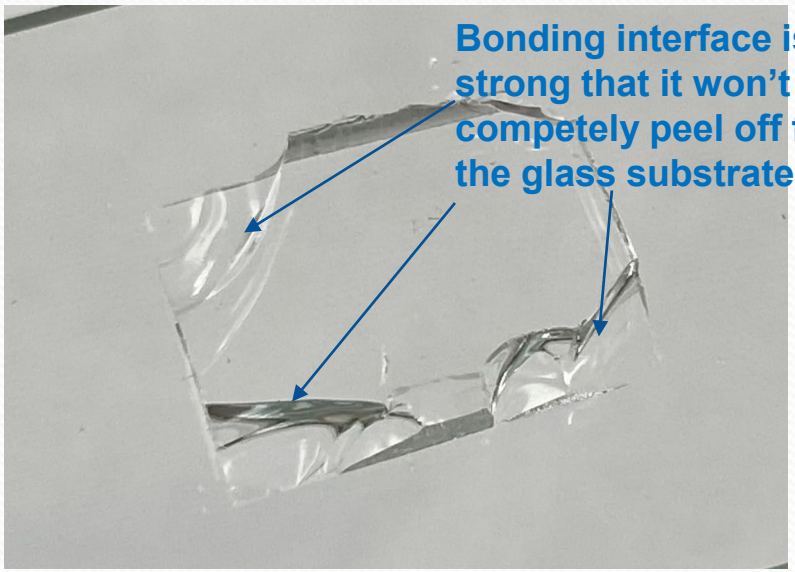
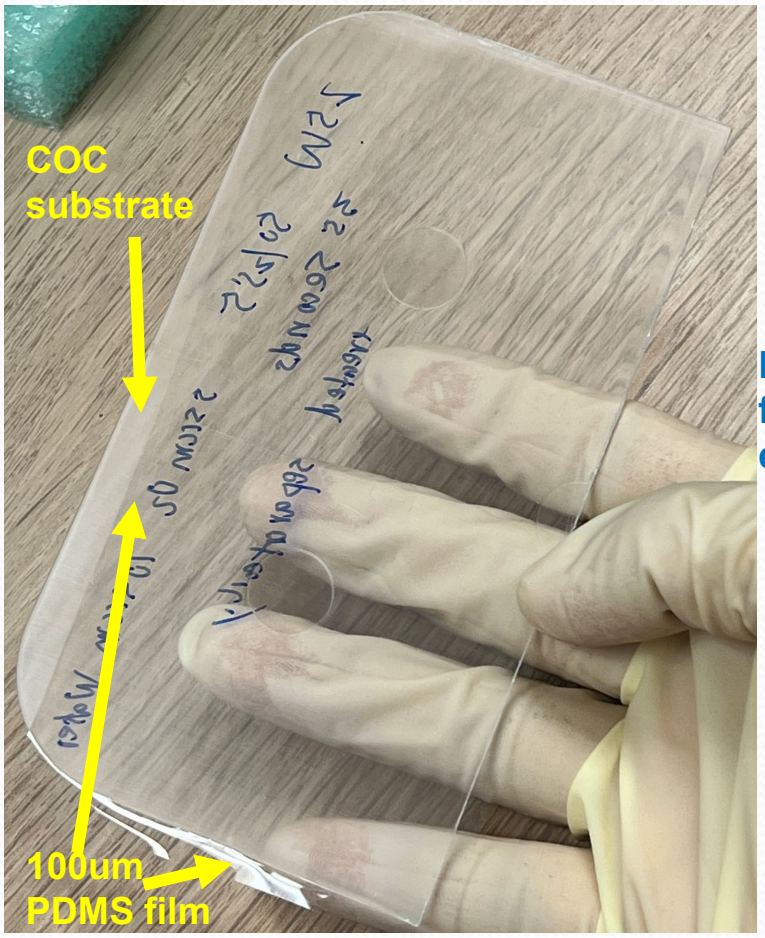


Figure 1, After plasma processing, PDMS bonds to glass immediately, trapped gas at the interface is automatically squeezed out. **No need to cure the PDMS/Glass bond in an oven for a couple of hours.**

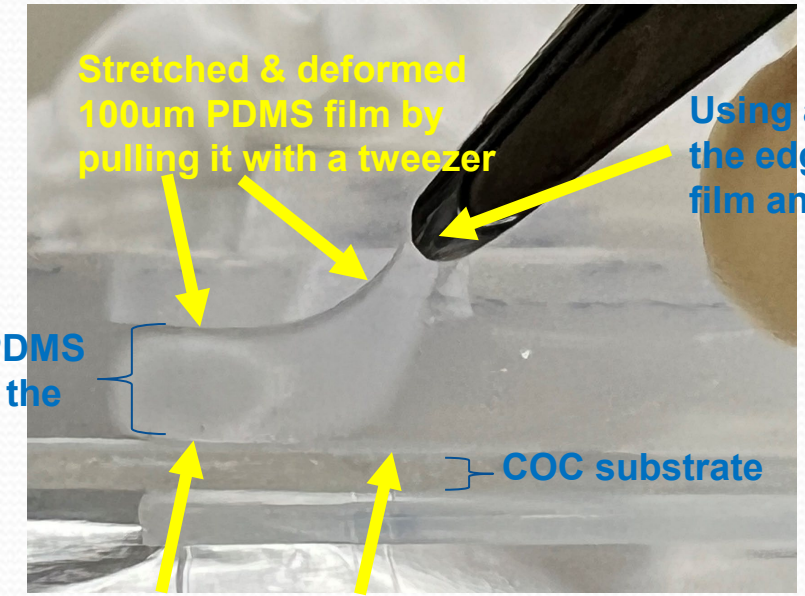
Figure 2, One minute after bonding, the user tries to break the PDMS/Glass bond. The bond is so strong that the PDMS/Glass bonding interface remains intact even after the top part of the PDMS was pulled off.

Figure 3, Another bonded PDMS block after we try to peel off the PDMS layer from glass.

PDMS – COC polymer bonding



Large area 100um PDMS bonded over COC polymer substrate



Interface of the 100um PDMS film and COC substrate remains intact under the stretching force, indicating strong bonding at the interface.

Recipe: 25watt rf power, 20% pulse, 5sccm oxygen, 10 sccm water vapor, duration 35 seconds.
Baking at 65 C overnight.

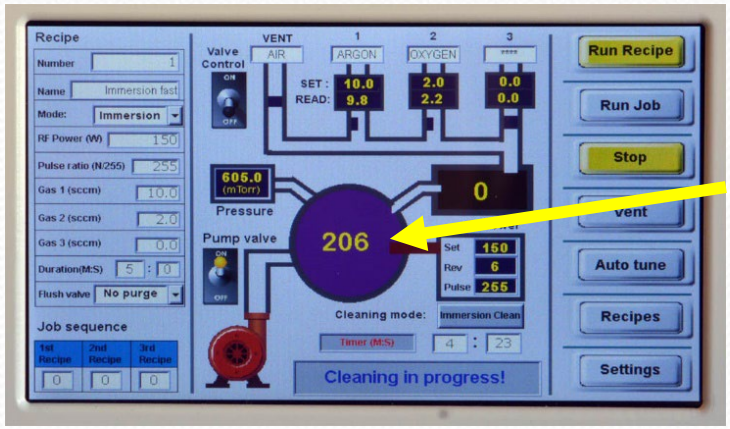
Baking is still required for PDMS-COC bonding Aminopropyltriethoxysilane (APTES) and 3-glycidoxypropyltrimethoxysilane (GPTMS) surface processing is not required with Tergeo plasma system + water vapor delivery kit

Why Tergeo is superior for PDMS bonding applications?

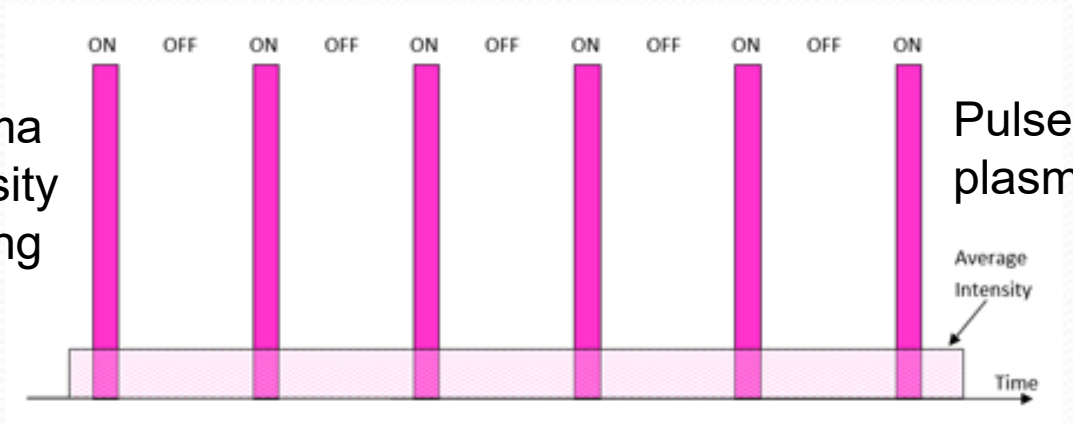
- The key for successful PDMS/Glass bonding process is to generate an extremely weak, uniform, repeatable air or oxygen plasma and existence of hydroxyl functional groups on the interface
- It's not easy for traditional low-cost plasma cleaners to generate extremely weak plasma reliably. To ignite the plasma, rf power has to be high enough to initialize the ionization process. On traditional plasma cleaners, once the plasma is ignited, it might have already been too strong for PDMS bonding applications. So the user can only process the PDMS samples for less than 10 seconds. However, the plasma is usually not very stable in the first 10 seconds.
- There are three key technologies on Tergeo for PDMS bonding.
  - Pulsed rf output allows Tergeo to ignite the plasma reliably with a higher rf field. But the averaged plasma intensity can still be extremely weak at low rf pulse ratio setting.
  - Unique plasma intensity sensor enables smart, automatic and reliable plasma ignition algorithm for extremely weak plasma. Plasma intensity sensor can also be used to monitor the process stability.
  - Unique water vapor (H_2O) delivery feature can ensure consistent and repeatable flow of water vapor into the plasma chamber during plasma cleaning and plasma processing. It can deposit high density of hydroxyl functional groups on the interface. **With added water vapor flow, Tergeo plasma system can bond PDMS to glass with processing time ranging from 10 seconds to more than 480 seconds instantly without baking.**

More control of plasma parameters

- Recipe based process control. Repeatable and reliable operation from day to day.
- Digital mass flow controlled (MFC) gas input. Precise, fast and repeatable.
- Multiple ways of adjusting the plasma intensity:
  - Rf power wattage (0-75W or 0-150W with 1-watt interval)
  - Pulse duty ratio of the rf output can be adjusted from 0% to 100% at 0.4% interval. Milliseconds pulse width. The linearity of the average plasma intensity vs rf power pulse ratio is significantly better than the linearity of the plasma intensity vs rf power wattage.
- Digital plasma intensity measurement takes the guess work out of the process development. The reading provides real-time feedback on the plasma intensity.

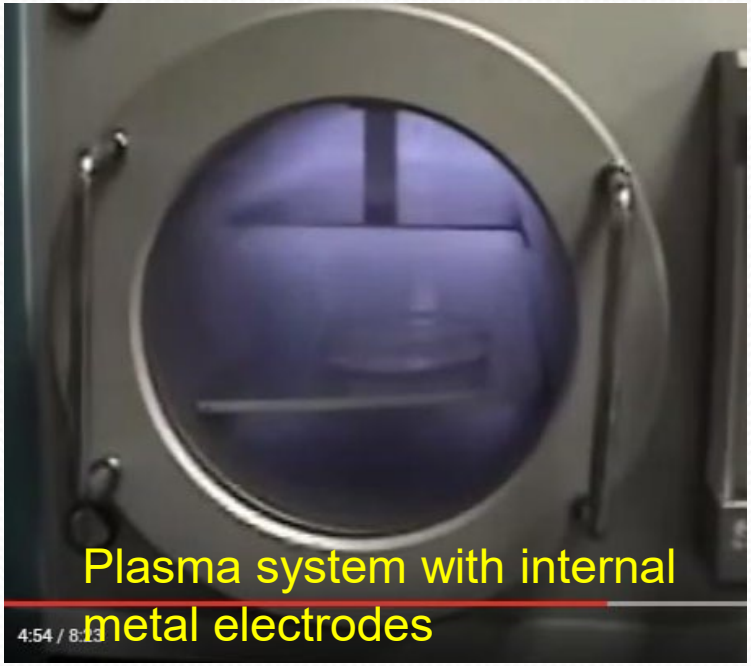


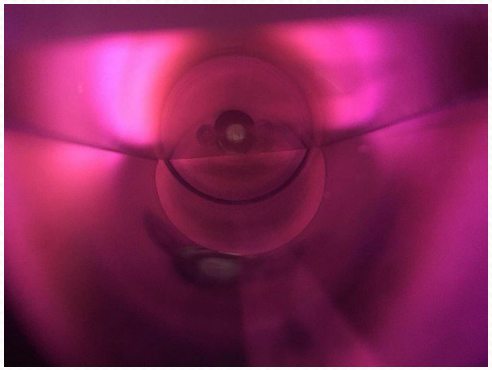
Plasma intensity reading



Pulsed plasma

Better uniformity and lower contamination





Inductive coil antenna design in some low cost plasma cleaner has very bad uniformity issue

Better uniformity. Plasma discharge technology in Tergeo plasma cleaner originates from the research carried out in the Plasma & Ion Source Technology at the Lawrence Berkeley National Laboratory. The difference in plasma color is because of the different process gas. Tergeo plasma cleaner clearly has much better uniformity. Bad uniformity means bad process control.

Lower contamination: Electrodes are placed outside of the quartz tube in Tergeo plasma cleaner. Ions can't reach the metal electrodes. If high voltage metal electrode is placed inside the plasma chamber, ions will be accelerated to high energy and sputter metal out of the electrodes. Metal will then deposit onto the samples and cause metal contamination issue. Metal sputtering contamination issue is especially severe if KHz rf power supply is used to generate the plasma.

Creating high-density OH* hydroxyl functional groups with water vapor plasma

Deliver controlled 0-10sccm water vapor (H2O) to the plasma chamber without heating up the water source.

Process gasses, such as ambient air, argon, oxygen, nitrogen, can render the sample surface hydrophilic. But they rely on the water moisture absorbed on the wall of the plasma chamber, sample surface, or by-products (H_2O) generated by oxygen oxidation of organic materials. Plasma can break up H_2O gas molecules and generate OH^* functional groups, which will then deposit on the sample surface and render the sample surface hydrophilic. Long & strong plasma cleaning can totally deplete the absorbed water inside the chamber. **Absolutely clean plasma chamber without any organic materials inside can't generate OH* functional group because there is no element H in the plasma chamber.**

- Generate high intensity water vapor plasma
- Deposit high density OH* hydroxyl functional group on the sample surface, especially on glass and silicon type inorganic sample surface.
- **Render the sample surface super hydrophilic and improve PDMS bonding strength and reliability**

Experimental results with water vapor

Step:

1. Wipe clean ten glass slides with IPA, and make sure there are no dust particles, residuals, or stains on the glass surface. Then plasma clean the ten glass slides in the chamber with 75watt, 10sccm air + 10sccm water for 5 minutes in the basic Tergeo plasma system. This step will remove any contaminations on the glass slides and deposit high-density OH* hydroxyl functional group on the glass.
2. Create a PDMS bonding recipe (A): 15watt, 50/255 pulse ratio, 10sccm air, 10sccm water, intensity reading: 100-130.
3. Place the pre-cleaned glass slides and PDMS into the chamber, and run recipe A with a duration range from 30s, 45s, 60s, 120s, 240s, and 480s. The bonding results are all good.
4. Create a PDMS bonding recipe (B): 15watt, 50/255 pulse ratio, 10sccm air only, intensity reading: 400-450.
5. Place the pre-cleaned glass slides and PDMS into the chamber. Before running the PDMS bonding recipe B, set the water flow to 90sccm (the system can only get 10-15sccm of water vapor flow) and let it flow for 2 -4 minutes to coat the sample and chamber with water. Then run recipe B with a duration range from 30s, 45s, 60s, 120s, and 240s. The bonding results are all good.

Conclusion:

I. Water vapor delivery kit can greatly improve the PDMS bonding performance.
II. It's essential to get the glass slides' surface clean and coat them with hydroxyl functional groups
III. There are two ways to admit water vapor. Either directly set 10sccm of water vapor flow or flow the water vapor before running the plasma PDMS bonding recipe.

Water vapor plasma can greatly increase the process window and bonding strength for PDMS bonding applications.

Reduce the adhesion on PDMS

- In some projects, researcher may want reduce the adhesiveness of PDMS by creating a thick layer of silica on the surface.
- Tergeo plasma system can generate high density oxygen plasma using 13.56MHz rf power to create a thick layer of silica on the surface of PDMS, which can make PDMS surface non-adhesive. Our former customers also reported that Tergeo plasma system is more efficient in etching PDMS layer to create a thicker layer of silica at lower rf power setting than competitive product on the market.

Customer feedback from a researcher at the University of California-Irvine:

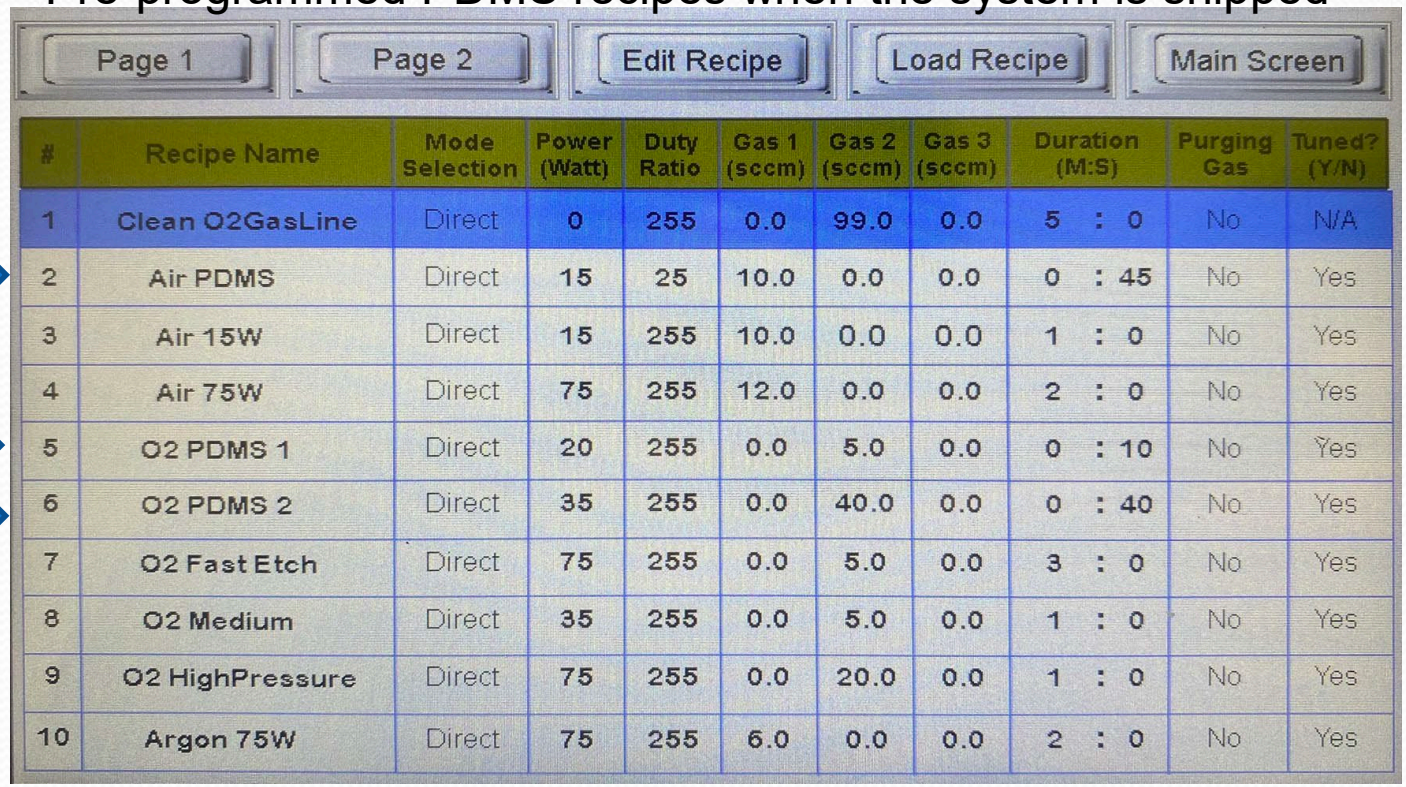
*"I was talking with my PI about your plasma system, and we are interested in your plasma system (direct+remote). We have check with 150W model in UIUC, and it worked well both general O2 direct plasma (surface cleaning and **silica layer formation on PDMS**) and remote Ar/H2 plasma. Regarding your system, can I ask a couple of questions?*

- ***We tried O2 plasma with 150W power for 5min, flowing 10 sccm oxygen. Indeed the condition was with lower plasma power than XXXXXX(a German brand) plasma (usually 250W-5min). But it turned out that thicker silicon oxide layer was formed on PDMS with lower power in PIE system.*** *Do you have any comparison to other company systems or can you let me know any specific difference in your system in terms of plasma power? We are considering what extent power we may need (75W to 300W as shown in the information sheet).*
- *We prefer short lead time product. Can you let me know general lead time and any model that has shorter lead time due to popularity? At this moment, we are considering TG100 (w/ 150W) for TP100 (w/ 150W) equipped with remote plasma capability.*

"

Intuitive to use, plug and play

Pre-programmed PDMS recipes when the system is shipped



#	Recipe Name	Mode Selection	Power (Watt)	Duty Ratio	Gas 1 (sccm)	Gas 2 (sccm)	Gas 3 (sccm)	Duration (M:S)	Purging Gas	Tuned? (Y/N)
1	Clean O2GasLine	Direct	0	255	0.0	99.0	0.0	5 : 0	No	N/A
2	Air PDMS	Direct	15	25	10.0	0.0	0.0	0 : 45	No	Yes
3	Air 15W	Direct	15	255	10.0	0.0	0.0	1 : 0	No	Yes
4	Air 75W	Direct	75	255	12.0	0.0	0.0	2 : 0	No	Yes
5	O2 PDMS 1	Direct	20	255	0.0	5.0	0.0	0 : 10	No	Yes
6	O2 PDMS 2	Direct	35	255	0.0	40.0	0.0	0 : 40	No	Yes
7	O2 Fast Etch	Direct	75	255	0.0	5.0	0.0	3 : 0	No	Yes
8	O2 Medium	Direct	35	255	0.0	5.0	0.0	1 : 0	No	Yes
9	O2 HighPressure	Direct	75	255	0.0	20.0	0.0	1 : 0	No	Yes
10	Argon 75W	Direct	75	255	6.0	0.0	0.0	2 : 0	No	Yes

Tergeo plasma system will be shipped with more than 10 pre-programmed recipes according to customer's applications. In this example, system was shipped with three preprogrammed PDMS recipes. Recipe 2 is PDMS bonding recipe using ambient air as the process gas. Recipe 5 and 6 are Oxygen PDMS bonding recipes using pure oxygen as the process gas.
When received, the customer can use Tergeo system for PDMS bonding right out of the boxes.

Customer testimonial

Dr. Marc Fouet at University of California – Berkeley:
"The Tergeo cleaner allows us to realize a simple PDMS-glass bonding process in a very efficient way. The integrated electronics saves space (no need for a computer) and the touch screen is responsive and convenient enough. The pumping time to reach the desired vacuum conditions is fairly short, which can be important to reduce noise exposure in the lab. Using the Tergeo plasma cleaner also enabled us to remove a step from our bonding process: ***the treatment works very well and a curing step in an oven to improve the bonding efficiency is no longer needed****."*

Dr. Patrick Tam at Ilumina San Francisco:
Their lab already had two plasma cleaners from other supplies. But the results weren't so good and were not repeatable. So they tried our Tergeo plasma cleaner. Here is their feedback: "*We could now use the plasma cleaner to bond PDMS over glass slides.* ***The performance of the plasma system is exceptionally good, and the process is very stable and reproducible****."*

Emilie DELPLANQUE, Laboratoire de Tribologie et Dynamique des Systèmes, CNRS Ecully cedex, France
"We have used our plasma system and it is really easy to use and the surface treatment is very fast. We have a good bonding between glass and silicon. Now, we will test it in tribological studies."

Customer Publications:

1. Patient-derived pancreas-on-a-chip to model cystic fibrosis-related disorders, **Nature** Communication vol 10, Article 3124(2019)
2. Replicating Arabidopsis Model Leaf Surfaces for Phyllosphere Microbiology, Scientific Reports – **Nature**, vol 9, article 14420 (2019)
3. Indirect co-culture of lung carcinoma cells with hyperthermia-treated mesenchymal stem cells influences tumor spheroid growth in a collagen-based 3-dimensional microfluidic model, **Cytotherapy**, Vol 23, issue 1, 2021.

Typical customers:

HARVARD UNIVERSITY

Berkeley
UNIVERSITY OF CALIFORNIA

Caltech

National Institutes of Health

MERCK

illumina®

Tergeo vs competitive products

Many of our customers already have multiple plasma systems from other vendors. But those systems don't work reliably or are hard to operate. So they decided to replace them with our Tergeo plasma system for better performance.

Tergeo

Other plasma systems