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PDMS bonding by means of a portable, low-cost corona system

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A hand-held corona treater is presented as an effective, inexpensive, and portable alternative for irreversible bonding of polydimethylsiloxane (PDMS) to glass.

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In recent years, micromolding of polydimethylsiloxane (PDMS) has become a ubiquitous tool for prototyping and testing microfluidic designs. A key advantage of PDMS, in addition to ease of use and excellent molding and optical qualities, is that it can be bonded irreversibly to glass or to itself without the use of adhesives.[1] Activation of bonding surfaces by oxygen plasma treatment is the established method for creating this permanent bond.[2]

Vacuum plasma systems typically employed for PDMS bonding are expensive, bulky, high maintenance pieces of equipment. As desire to fabricate PDMS prototypes moves beyond specialized engineering laboratories, a need is arising for simpler, more economical means of surface activation. Plasma 'guns' such as the Tri-Star Duradyne offer a somewhat less cumbersome alternative to traditional vacuum plasma systems, however the cost can still be prohibitive. These units eliminate the need for a vacuum chamber, but retain the use of controlled gas flows to achieve the desired plasma. Recently, Ginn and Steinbock reported successful bonding of PDMS using a standard microwave oven to generate plasma.[3] In this system, samples to be bonded were placed into a desiccator, which was purged with oxygen and then evacuated to 10^{-3} Torr. A small piece of steel wire at the bottom of the desiccator created a spark, initiating a plasma when the desiccator was exposed to microwaves. Here, we present the use of a hand-held corona treater as another effective, inexpensive, and highly portable alternative for PDMS bonding.

The corona treater tested was a model BD-20AC with a custom power-line filter, purchased from Electro-Technic Products Inc.† The unit was supplied with three electrodes; a straight spring, a one inch disc, and a two and a half inch wire (see Fig. 1). The high potential of the electrode ionizes surrounding air, creating a localized plasma or "corona." The corona plasma differs from those mentioned earlier, in that it is established in room air at atmospheric pressure. Thus, no vacuum pumps or gas cylinders are required, and bonding can be performed on any convenient non-conducting surface.

Bonding is achieved by placing a clean glass slide or cover slip (a variety of brands have been used) and the PDMS sample bonding side up on a non-conducting surface. The glass is wiped with methanol to remove residues that may be present out of the box. The corona is adjusted to a relatively low level to produce a stable but soft corona with minimal crackling and sparking. The setting may need to be adjusted depending on atmospheric conditions. The wire electrode is passed back and forth approximately ¼ inch above each bonding surface for five to twenty seconds, depending on the size of the piece. Treated surfaces are then pressed together and left undisturbed for at least one hour for bonding to take effect. Leaving samples overnight insures complete bonding.

The corona bonding process is difficult to quantitate, given that the level of treatment depends on a non-numerical power setting, distance of a hand-held electrode from the sample, treatment time, and size of the sample. Atmospheric conditions may also be a factor. Fortunately, bonding is achieved over a wide range of treatments, as evidenced by contact angle measurements. The amount of contact angle reduction for water on PDMS is known to be proportional to the dose of plasma. A crude experiment was conducted in which a variety of treatments, varying power, time, and electrode type, were tested by simultaneously activating two ¾ inch squares of PDMS (Sylgard184 at a 10 : 1 ratio). One square was assessed for contact angle reduction with deionized water, and the other was tested for bonding to similarly treated glass. Resulting contact angles ranged from approximately 92° (native PDMS has a contact angle of 105°) to 0° or too low to measure. After 1 hour, all samples except that with the 0° contact angle were bonded solidly. Even an over-treated sample with a 0° contact angle will bond if left undisturbed overnight, however experience has shown that more moderate treatments are preferable. It should be noted that a zero degree contact angle

Fig. 1 Photo showing a model BD20-AC hand-held corona treater with its three interchangeable electrodes.

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is desirable for the naturally hydrophilic glass surface. A non-zero contact angle on glass indicates the presence of surface contaminants, which are removed by plasma treatment.

Normal, day-to-day use of this system in our laboratory has given dependable, uniform bonding. In this particular situation, 1 × 3 inch microscope slides are bonded to pieces of PDMS of roughly the same size. The 2½ inch electrode is ideal in that the corona is wide enough to cover a 3 inch surface. A treatment time of 10–15 seconds per piece is used. The corona system has numerous advantages over conventional plasma chambers. Since the corona system can be used nearly anywhere, PDMS samples can be treated and bonded immediately upon removal from the master, minimizing the chance of contamination, and eliminating the need for cleaning. Additionally, the fact that a vacuum chamber does not need to be pumped down, saves time. Another less obvious advantage is that within the first five minutes after contact, PDMS can be peeled from the glass and repositioned, with normal bonding still occurring in the majority of cases. This is not possible with most plasma treatments, in which bonding is initiated on contact. The mechanism for this difference in the onset of bonding is not known. The corona treater also has useful applications beyond bonding, such as creating a hydrophilic environment inside a previously constructed microchannel. Insertion of the spring tip into an access hole will result in a corona running through the length of the channel, thereby treating the inner surfaces. The resulting increase in surface energy can facilitate filling of small or complex channels with aqueous solutions.[1] Even though channels are rendered hydrophilic from the initial bonding process, PDMS reverts to a hydrophobic state in a matter of minutes to days, depending on conditions.[4] Therefore the ability to reactivate a channel just prior to use is beneficial. Finally, polypropylene connectors, often kept out of conventional plasma chambers to avoid residue build-up, can be treated safely on the bench-top. This greatly enhances the strength with which they bond to adhesives, making them less likely to break off of a device during use.‡

The corona treater is safe and easy to use, however some precautions do need to be observed. First, the corona produces a significant amount of ozone, and should only be used in an area with good ventilation. Secondly, the unit produces radio frequency (RF) noise, which has the potential to affect other equipment. The unit must be used on a non-conducting surface and should be kept at least three feet away from digital devices. RF transmitted through the air was repeatedly seen to reset a digital stopwatch to midnight on January 1st. Likewise, the time and temperature settings of a digital hotplate were reset when the corona treater was brought too close. Fortunately, this effect is confined to within two or three feet of the unit. However, RF noise can also feed back through the power-line and affect sensitive instruments elsewhere on the circuit. Discussions with Electro-Technic led them to adapt a unit with a power-line filter. This has solved all problems of RF interference through the building wiring. The line filter is strongly recommended for any laboratory with sensitive electronic equipment.† It should also be noted that while this corona treater is akin to Tesla coils commonly used for leak detection, it has a higher frequency output that facilitates formation of a stable corona around the electrode. Standard leak detectors can achieve marginal bonding but are far less effective.

Because of its low cost, ease of use, and portability, the hand-held corona treater opens the possibility of fabricating microfluidic devices to nearly any laboratory. This could have a particular impact in allowing biology laboratories to make microfluidic devices for their own testing, rather than being completely dependent on collaborating engineers. As a result, projects may be enabled that would otherwise not have been undertaken.

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† At present, the modified BD-20AC, containing the recommended power-line filter, must be requested specially from Electro-Technic Products as: Model BD-20AC Hand-Held Laboratory Corona Treater, 115 V, with power-line filter, order number 12051A-10. At the time of writing, this unit costs $430.00 and has a lead-time of one week upon receipt of the order.

‡ Corona treatment of polypropylene and other plastics to improve the effectiveness of adhesives is an established technique, widely employed in industry.