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Title: Construction Methods for Hybrid Polycarbonate-Silicon Microfluidic Devices

Authors and Affiliations:

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Author Questionnaire

- 1. Microscopy:** Does your protocol require the use of a dissecting or stereomicroscope for performing a complex dissection, microinjection technique, or something similar? **No**

- 2. Software:** Does the part of your protocol being filmed include step-by-step descriptions of software usage? **No**

- 3. Filming location:** Will the filming need to take place in multiple locations? **No**

- 4. Testimonials (optional):** Would you be open to filming two short testimonial statements **live during your JoVE shoot**? These will **not appear in your JoVE video** but may be used in JoVE's promotional materials. **No**

Current Protocol Length

Number of Steps: 21

Number of Shots: 51

Introduction

Videographer: Obtain headshots for all authors available at the filming location.

INTRODUCTION:

~~REQUIRED: Summarize your research focus and the main questions it aims to answer.~~

- 1.1. **Jackie Kading:** Our research focuses on bonding hybrid microfluidic devices for prototyping in academic lab settings. We aim to answer the question of what are low-cost yet optimal bonding strategies for a hybrid microfluidic channel.

- 1.1.1. INTERVIEW: Named talent says the statement above in an interview-style shot, looking slightly off-camera

Videographer's NOTE: Better visual take of 1.1.1 is slated as take 2. Other visuals are also provided.

~~Describe the research gap or limitation in existing methods and how this protocol addresses them.~~

- 1.2. **Jackie Kading:** Bonding thermoplastics to rigid substrates in hybrid microfluidics is challenging, and conventional high-temperature, high-pressure methods are unsuitable; this protocol provides a practical, research-friendly bonding approach.

- 1.2.1. INTERVIEW: Named talent says the statement above in an interview-style shot, looking slightly off-camera

Videographer's NOTE: Better visual take of 1.2.1 is slated as take 2. Other visuals are also provided.

CONCLUSION:

~~What does this protocol allow researchers to study or measure?~~

- 1.3. **Jackie Kading:** This protocol allows researchers to study different low-cost bonding modalities suitable for bonding hybrid microfluidic devices in a laboratory setting.

- 1.3.1. INTERVIEW: Named talent says the statement above in an interview-style shot, looking slightly off-camera

~~Describe the most important consideration or challenge when performing this protocol.~~

- 1.4. **Jackie Kading**: The most important consideration when performing this protocol is ensuring precision in both the design fabrication and alignment of the layers for a leak-tight interface and adequate bond surface area.

1.4.1. INTERVIEW: Named talent says the statement above in an interview-style shot, looking slightly off-camera

~~How can future studies build on this work? Describe the questions or research directions that can be investigated next.~~

- 1.5. **Jackie Kading**: Future studies can compare sealing surface areas across bonding methods and evaluate this protocol's applicability to hybrid microfluidic systems incorporating brittle or diverse substrate materials.

1.5.1. INTERVIEW: Named talent says the statement above in an interview-style shot, looking slightly off-camera

Videographer: Obtain headshots for all authors available at the filming location.

Protocol

***Videographer:** Please always record an audio slate while filming each shot mentioned in the shotlist.*

2. Solvent Bonding of Polycarbonate Microfluidic Device with Integrated Silicon Chip

Demonstrators: Jackie Kading, Charlotte Li

- 2.1. To begin, obtain the polycarbonate housing to achieve [1] a flat bonding surface [2]. After cleaning the components, integrate the silicon chip using epoxy, and leave the assembly to cure, ensuring any residual gaps are sealed with fresh epoxy [3].
 - 2.1.1. WIDE: Talent placing the polycarbonate housing on the work surface.
 - 2.1.2. Close-up of showing the polycarbonate housing.
 - 2.1.3. Talent placing the silicon chip into the housing using epoxy.
- 2.2. For solvent bonding, laser-cut the adhesive tape to match the shape of the channel walls [1] and apply adhesive tape to define the channel walls [2].
 - 2.2.1. Talent laser-cutting the adhesive tape to match the shape of the channel walls. **Videographer's NOTE:** Included multiple shots and angles here including wide establishing, upclose of adhesive tape getting put in, overhead of laser cutting, and adhesive being removed. Process is the same as 3.1.2.
 - 2.2.2. ~~Talent applying adhesive tape to define the channel walls.~~ **Note:** This shot is deleted and encompassed in 2.3
- 2.3. To apply adhesive tape, remove 1 liner layer from the tape [1]. Then, align and apply the tape to the channel wall surfaces using dowel pins for alignment [2]. **Note:** The narration for deleted 2.2.2 is added concisely in 2.3
 - 2.3.1. Talent removing 1 liner layer from the tape. **Videographer's NOTE:** Take 2 is better as thin layer can be hard to remove.
 - 2.3.2. Talent aligning and applying the tape to the channel wall surfaces with dowel pins.
- 2.4. To coat the fluidic channel, add enough one-percent polyvinyl alcohol covering the entire area [1] [2] and allow the polyvinyl alcohol solution to dry completely at room temperature [3]. **NOTE:** Based on videographer's note, the narration is edited to show addition and placing the plate aside. If we have visuals for 2.4.2, can be played along

with part of adding the alcohol. However, the video editor can see how it fits the best after reviewing the footage.

2.4.1. Talent adding polyvinyl alcohol to the fluidic channel and setting aside.

Videographer's NOTE: Talent sets channel aside in 2.4.1

2.4.2. Talent showing the fully covered fluidic channel area.

2.4.3. Talent leaving the polyvinyl alcohol-coated channel aside to dry at room temperature.

2.5. To remove the adhesive mask once the polyvinyl alcohol layer has fully cured [1], carefully peel off the double-sided adhesive, leaving a polyvinyl alcohol-coated fluidic channel [2]. Inspect and clean any residual adhesive from the channel walls if necessary to ensure the channel half-plate contains cured polyvinyl alcohol and remains adhesive-free [3]. **Note:** VO has been edited by authors based on visuals filmed

2.5.1. Talent showing the fully cured device ~~and starting to removing the adhesive mask from the cured device.~~ **Note:** Removing the adhesive from cured device happens in 2.5.2

2.5.2. Talent peeling off the double-sided adhesive fully to leave a polyvinyl alcohol-coated fluidic channel.

2.5.3. Shot of the channel ~~walls and cleaning residual adhesive.~~ half-plate with cured PVA and without adhesive. **Note:** Both author and videographer have changed this shot's description.

2.6. Align the top and bottom polycarbonate housings using dowel pins [1].

2.6.1. Talent aligning the top and bottom polycarbonate housings with dowel pins.

Videographer's NOTE: Take 2 better.

2.7. ~~Next, fill a 5-milliliter syringe with a 30-gauge needle with the chosen solvent, such as dichloromethane or acetone [1].~~ Position the tip of the syringe equipped with 30-gauge needle and pre-filled with dichloromethane or acetone at the lip or ledge created in the device design [2]. Carefully dispense the solvent along the lip or ledge on both sides of the assembly, allowing the solvent to wick into the bonding interface and reach the polyvinyl alcohol barrier [3].

~~2.7.1. Talent filling a 5-milliliter syringe fitted with a 30-gauge needle with solvent.~~

NOTE: As per author's and videographer's notes, talent had syringe prefilled with water for demonstration, so filling the syringe step was not filmed. VO has been edited accordingly.

- 2.7.2. Talent positioning the syringe tip at the lip or ledge of the assembly.
- 2.7.3. Talent dispensing solvent along both sides of the lip or ledge so it wicks into the bonding interface. **NOTE: 2.7.3 combined into 2.7.1 - 2.7.3 footage. 2.7.1 is not filmed.**

2.8. Then, place a moderate weight of approximately 2 to 3 pounds evenly over the assembled device and allow the device to cure fully at room temperature for 10 to 15 minutes [1].

- 2.8.1. Talent placing a moderate weight evenly over the assembled device for curing and setting the sample aside.

Videographer's NOTE: Misslabeled as 2.7.3. - File TLV_2748

2.9. Ensure no large bubbles are present to reduce points of failure [1].

- 2.9.1. Talent viewing the sample for bubbles.

2.10. After curing, flow 80 degrees Celsius deionized water through the fluidic channel at low flows of 1 to 5 milliliters per minute for a minimum of 3 hours [1]. Inspect the device visually for residual polyvinyl alcohol in the channel [2] and repeat the water flow until no polyvinyl alcohol is visually apparent [3].

- 2.10.1. Talent flowing deionized water through the fluidic channel.
- 2.10.2. Talent visually inspecting the channel for residual polyvinyl alcohol.
- 2.10.3. Talent turning on the water flow again.

3. Low-Density Polyethylene (LDPE) Bonding of Polycarbonate Microfluidic Device

Demonstrators: Jackie Kading, Charlotte Li

3.1. To prepare a 100 to 200-micrometer low-density polyethylene sheet, set the referenced desktop laser cutter to 75% power and 100% speed [1]. Laser-cut the sheet to match the shape of the channel wall regions [2].

- 3.1.1. Show the referenced desktop laser cutter settings set to **75% power** and **100% speed** ~~for a 100 to 200 micrometer low density polyethylene sheet~~
- 3.1.2. Talent operating the laser-cutter to prepare ~~cutting the low density polyethylene sheets to match~~ the shape of the channel wall regions. Show the laser cutter operating

Videographer's NOTE: Included two takes. One wide and one close up of screen.

Talent did not have extra uncut low-density polyethylene sheets, so not footage of cutting happening, but process is the exact same as 2.2.1

Note: Author has modified the shot description to match the captured shot. If required and possible to reuse 2.2.1, use it

- 3.2. Inspect the laser-cut low-density polyethylene sheets for ash, residue, or particulates [1]. Rinse the sheets thoroughly with isopropyl alcohol and allow them to dry completely [2].

3.2.1. Talent inspecting the laser-cut low-density polyethylene sheets for ash, residue, or particulates

3.2.2. Talent rinsing the sheets with isopropyl alcohol and leaving them to dry completely.

Note: Author mentioned to merge 3.2.1 and 3.2.2 but no such notes from the videographer

- 3.3. Now, align the low-density polyethylene cutouts onto the side walls of the fluid channel using dowel pins [1]. Place the top polycarbonate piece onto the bottom assembly to create the fluidic channel with the low-density polyethylene layers at the bonding interface [2].

3.3.1. Talent aligning the low-density polyethylene cutouts onto the side walls of the fluid channel with dowel pins

3.3.2. Talent placing the top polycarbonate piece onto the bottom assembly to create the fluidic channel with the low-density polyethylene layers at the bonding interface.

Note: Author mentioned to combine 3.3.1 and 3.3.2 into one shot but no such notes from the videographer

- 3.4. To bond the assembly, place the assembled housing into a ~~preheated~~ programmable oven set to 145 degrees Celsius with a temperature sensor [1]. Then, position a calibrated weight such as a metal plate on top of the assembly to apply moderate pressure of 2 to 3 pounds per square inch [2].

3.4.1. Talent placing the assembled housing into a ~~preheated~~ programmable oven set to 145 degrees Celsius with a temperature sensor. **Author's NOTE:** Note that oven demonstrated in this video starts as "off," as this oven is programmable after it is closed to quickly reach goal temperature and does not need to preheat. Other types of ovens may need to preheat, so that is in the instruction.

3.4.2. Talent placing a calibrated weight such as a metal plate on top of the assembly.

- 3.5. After 2 hours, remove the assembly from the oven [1]. Ensure even low-density polyethylene transparency across the entire bonded surface area [2] and let the device

to cool to room temperature [2].

3.5.1. Talent removing the assembly from the oven after 2 hours.

Videographer's NOTE: This was recorded as part of 3.4.2. The talent placed and removed the assembly from the oven multiple times.

3.5.2. Shot of the bonded surface area for even low-density polyethylene transparency.

3.5.3. Talent keeping the sample aside. **Note:** Not filmed.

4. Mechanical Gasket Sealing of Polycarbonate-Silicon Microfluidic Device

4.1. Cut the gasket cord material to the required length to match the fluidic channel path [1]. Place the gasket cord into the gasket gland on the bottom polycarbonate housing, ensuring a snug and continuous fit along the entire path [2]. Align the top polycarbonate piece with the bottom piece to define the boundaries of the fluidic channel [3]. **Note:** 4.1.3 was added by the author and a corresponding VO narration was provided.

4.1.1. Talent cutting the gasket cord material to the required length.

4.1.2. Talent placing the gasket cord into the gasket gland on the bottom polycarbonate housing.

Added shot: 4.1.3. Talent aligning the top and bottom housing half plates to form the bounds of the fluidic channel.

4.2. Align the top polycarbonate piece with the bottom piece [1], then insert bolts through the top layer and into the hex nut, adding washers or a compression plate as needed to evenly distribute pressure [2]. **Note:** This narration has been modified as per the notes.

4.2.2 Talent aligning the top and bottom pieces. **NOTE:** the videographer mentioned that the talent aligns top and bottom pieces and then inserts the bolt. The VO has been edited accordingly and shots are flipped in the script and 4.2.2 shot has been modified.

4.2.1. Talent inserting bolts through the top layer into the hex nut with washers or a compression plate.

4.3. To tighten the bolts, hand-tighten each screw to hold the bolts and device in place [1]. Use a torque wrench to tighten each screw, moving in a cross pattern [2]. Tighten to 0.5 pound-inch to avoid cracking the silicon chip or deforming the polycarbonate housing and tighten further as necessary [3].

4.3.1. Talent hand-tightening each screw to secure the device. **Author's Note:** This shot needs to be cross referenced with videographer's edits, as combining this shot 4.3.1 (hand tightening screws) with 4.2.1 (placing screws) was considered during filming. Please proceed with what the videographer blocked in his submitted footage, whether he decided to combine or run separate shots.

- 4.3.2. Talent using a torque wrench to tighten screws in a cross pattern.
- 4.3.3. Talent setting and applying 0.5 pound-inch torque on the screws.

5. Pressure and Flow Characterization of the Hybrid Microfluidic Device

- 5.1. Prepare to connect the hybrid microfluidic device to a fluidic circuit [1]. Using peristaltic pump tubing, connect a water reservoir, roller pump, pressure sensor, and the hybrid microfluidic device in series [2]. Position the pressure sensor as close to the device inlet as possible to ensure accurate pressure measurements [3].

- 5.1.1. Talent arranging the hybrid microfluidic device and tubing for circuit connection.
- 5.1.2. Talent connecting the water reservoir, roller pump, pressure sensor, and device in series using peristaltic pump tubing
- 5.1.3. Talent positioning the pressure sensor close to the device inlet.

Note: Author mentioned to combine 5.1.2 and 5.1.3 into one shot but no such notes from the videographer

- 5.2. Pump water through the circuit at an initial flow rate of 10 milliliters per minute [1]. Increase the flow rate in increments of 10 milliliters per minute every minute [2]. Measure and record the pressure at each flow rate [3]. If additional pressure is required, add a needle restriction downstream of the device to increase circuit resistance, and define the rated pressure as the point at which the first visible leak occurs[4].

- 5.2.1. Talent initiating water flow through the circuit at 10 milliliters per minute.
- 5.2.2. Talent adjusting the flow rate in increments of 10 milliliters per minute.
- 5.2.3. Talent measuring and recording pressure readings at each flow rate.

Note: Author mentioned to combine 5.2.2 and 5.2.3 into one shot but no such notes from the videographer

- 5.2.4. Talent adding a needle restriction downstream of the device.

- 5.3. Finally, insert a second pressure sensor immediately downstream of the device using the same circuit [1]. Flow water at a selected flow rate of 10 milliliters per minute [2] and calculate the pressure drop across the device as the difference between the pre-device and post-device pressure measurements [3].

- 5.3.1. Talent inserting a second pressure sensor downstream of the device.
- 5.3.2. Talent flowing water through the circuit at 10 milliliters per minute.
- 5.3.3. Talent working at the computer table.

Results

6. Results

6.1. The gasket-based mechanical sealing strategy was successfully used to obtain a prototype [1].

6.1.1. LAB MEDIA: Figure 4. *Video editor: Show all panels; zoom in on panel C* **Note:**
The author has removed the point “zoom in on panel C”

6.2. The gasket-based configuration sustained pressures up to 239 millimeters of mercury before leakage [1] and showed a low-pressure drop of 3 millimeters of mercury [2].

6.2.1. LAB MEDIA: Table 1. *Video editor: Highlight the cell in the row “Rated Pressure (mmHg)” under the column “Gasket” showing 239 +or- 22.*

6.2.2. LAB MEDIA: Table 1. *Video editor: Highlight the cell in the row “Pressure Drop (mmHg) at 10 mL/min” under the column “Gasket”.*

Pronunciation Guides:

1. Polycarbonate
Pronunciation link: <https://www.merriam-webster.com/dictionary/polycarbonate>
IPA: /ˌpɑːliˈkɑːrbəˌneɪt/
Phonetic Spelling: pah·lee·kaar·buh·nayt
2. Microfluidic
Pronunciation link: <https://www.howtopronounce.com/microfluidic>
IPA: /ˌmaɪkroʊfluˈɪdɪk/
Phonetic Spelling: my·kroh·floo·id·ik
3. Epoxy
Pronunciation link: <https://www.merriam-webster.com/dictionary/epoxy>
IPA: /ɪˈpɑːksi/
Phonetic Spelling: ih·paak·see
4. Dichloromethane
Pronunciation link: <https://www.merriam-webster.com/dictionary/dichloromethane>
IPA: /daɪˌklɔːroʊˈmiːθeɪn/
Phonetic Spelling: dye·klor·oh·mee·thayn
5. Acetone
Pronunciation link: <https://www.merriam-webster.com/dictionary/acetone>
IPA: /ˈæsəˌtoʊn/
Phonetic Spelling: a·suh·tohn

6. Polyvinyl
Pronunciation link: <https://www.merriam-webster.com/dictionary/polyvinyl>
IPA: /ˌpɑːliˈvaɪnəl/
Phonetic Spelling: pah·lee·vy·nuhl
7. Alcohol
Pronunciation link: <https://www.merriam-webster.com/dictionary/alcohol>
IPA: /ˈælkəˌhɔːl/
Phonetic Spelling: al·kuh·haawl
8. Deionized
Pronunciation link: <https://www.merriam-webster.com/dictionary/deionized>
IPA: /diˈaɪəˌnaɪzd/
Phonetic Spelling: dee·eye·uh·nyzd
9. Polyethylene
Pronunciation link: <https://www.merriam-webster.com/dictionary/polyethylene>
IPA: /ˌpɑːliˈεθəˌliːn/
Phonetic Spelling: pah·lee·eth·uh·leen
10. Isopropyl
Pronunciation link: <https://www.merriam-webster.com/dictionary/isopropyl>
IPA: /ˌaɪsəˈprɒpəl/
Phonetic Spelling: eye·suh·proh·puhl
11. Programmable
Pronunciation link: <https://www.merriam-webster.com/dictionary/programmable>
IPA: /ˈprɒɡræməbəl/
Phonetic Spelling: ɜrɒm·gram·uh·buhl
12. Transparency
Pronunciation link: <https://www.merriam-webster.com/dictionary/transparency>
IPA: /trænsˈperənsi/
Phonetic Spelling: trans·pair·uhn·see
13. Gasket
Pronunciation link: <https://www.merriam-webster.com/dictionary/gasket>
IPA: /ˈɡæskɪt/
Phonetic Spelling: gas·kit
14. Torque
Pronunciation link: <https://www.merriam-webster.com/dictionary/torque>
IPA: /tɔːrk/
Phonetic Spelling: tork
15. Peristaltic
Pronunciation link: <https://www.merriam-webster.com/dictionary/peristaltic>
IPA: /ˌperəˈstɔːltɪk/
Phonetic Spelling: peh·ruh·staal·tik
16. Reservoir
Pronunciation link: <https://www.merriam-webster.com/dictionary/reservoir>

IPA: /'rezər,vwɑ:r/

Phonetic Spelling: reh·zer·vwahr

17. Sensor

Pronunciation link: <https://www.merriam-webster.com/dictionary/sensor>

IPA: /'sensər/

Phonetic Spelling: sen·ser

18. Circuit

Pronunciation link: <https://www.merriam-webster.com/dictionary/circuit>

IPA: /'sɜ:kɪt/

Phonetic Spelling: sur·kit

19. Increment

Pronunciation link: <https://www.merriam-webster.com/dictionary/increment>

IPA: /'ɪŋkrəmənt/

Phonetic Spelling: ing·kruh·ment

20. Characterization

Pronunciation link: <https://www.merriam-webster.com/dictionary/characterization>

IPA: /,kærəktərə'zeɪʃən/

Phonetic Spelling: ka·ruk·tuh·ruh·zay·shuhn