FINAL SCRIPT: APPROVED FOR FILMING

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Title: Optimized Fabrication Procedure for High-Quality Graphene-Based Moiré Superlattice Devices

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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? **Yes, all done**

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

Current Protocol Length
Number of Steps: 32
Number of Shots: 60

Introduction

1.1. **Pablo Jarillo-Herrero:** Our research is focused on the quantum electronic properties of two-dimensional materials and their heterostructures, aiming to discover and investigate new quantum phenomena and develop novel electronic devices.

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

What significant findings have you established in your field?

1.2. **Pablo Jarillo-Herrero:** We pioneered the field of "twistronics", where the properties of 2D materials heterostructures change as a function of the angle between the layers. The most impactful discovery was superconductivity in magic-angle graphene.

1.2.1. INTERVIEW: Named Talent says the statement above in an interview-style shot, looking slightly off-camera. *Suggested B.roll: 2.8*

What are the current experimental challenges?

1.3. **Shuwen Sun:** Achieving a precise twist angle remains challenging due to heterostrain, disorder, and lattice relaxation introduced during the nanofabrication process, which often lead to device inhomogeneity and limit reproducibility across samples.

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

How will your findings advance research in your field?

1.4. **Shuwen Sun:** This protocol reflects our experience optimizing each fabrication step to improve uniformity and yield, enabling more researchers to reliably build high-quality graphene moiré devices and accelerate progress in this field.

1.4.1. INTERVIEW: Named Talent says the statement above in an interview-style shot, looking slightly off-camera. *Suggested B.roll:3.4*

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

2. Laser Patterning and Pickup of Top Hexagonal Boron Nitride Layer

Demonstrator: Shuwen Sun

2.1. To begin, place a graphene wafer on the sample stage of the transfer setup integrated with a supercontinuum laser **[1].** Use **Peek Through** to make the **Inkscape** window semi-transparent while floating above the camera window **[2]**. Use the **Draw Bezier curves and straight lines** function in **Inkscape** to outline the graphene boundary and the planned laser-cutting lines **[3]**.

2.1.1. WIDE: Talent places the graphene wafer on the sample stage.

Added Shot: SCREEN: 68230_2.1-2.3_3.x.mp4 00:11-00:18

2.1.2. SCREEN: 68230_2.1-2.3_3.x.mp4 01:54-02:21 .

2.2. Now power on the laser and increase the intensity until the beam spot is visible **[1]**. Adjust the sample stage to align the beam spot with the start of a planned laser-cutting line **[2-TXT]**.

2.2.1. Talent switching on the laser and gradually increasing intensity.
AND
SCREEN: 68230_2.1-2.3_3.x.mp4 02:58-03:08
Video Editor: Please play both shots side by side

2.2.2. Talent adjusting the stage so the laser spot aligns with the beginning of a cutting line. **TXT: Adjust laser intensity to suitable level**
AND
SCREEN: 68230_2.1-2.3_3.x.mp4 03:26-03:29
Video Editor: Please play both shots side by side

2.3. Next, move the sample stage to guide the beam spot along the planned laser-cutting line **[1]**. After zeroing the laser intensity, inspect the laser-cutting line **[2-TXT]**.

2.3.1. Talent guiding the stage to trace along the laser-cutting path.
AUTHOR'S NOTE: Taken as 2 shots

2.3.2. SCREEN: 68230_2.1-2.3_3.x.mp4 03:37-03:51 **TXT: Repeat steps until all planned lines are laser cut**

2.4. To pickup the top hexagonal boron nitride flake, adjust the orientation of the flake until the straight edge is vertical and positioned on the right side **[1-TXT]**.

2.4.1. SCREEN : 68230_2.4-2.10.mp4 00:00-00:19. **TXT: Outline flake boundary in Inkscape**

2.5. Gently clamp the glass slide with the PC/PDMS *(P-C-and-P-D-M-S)* stamp inside the socket at a downward tilt angle of 2 to 3 degrees **[1]**. Slide the socket to the left using the sliding tray until the glass slide is positioned above the sample wafer then manually lock it in place **[2]**.

2.5.1. Talent clamping the glass slide into the socket at a tilt. **TXT: PC/PDMS: polycarbonate/Polydimethylsiloxane**

2.5.2. Shot of the socket being slide to the left and locked.

2.6. After setting the sample stage temperature to 50 degrees Celsius, engage the glass slide downward using the Z direction actuator **[1-TXT]**. Focus the microscope on the polycarbonate film and inspect the surface cleanness **[2]**.

2.6.1. Talent engaging the actuator to lower the stamp. **TXT: Speed: 1 mm/s until stamp is 2 mm above wafer**

2.6.2. SCREEN: 68230_2.4-2.10.mp4 01:27-01:31

2.7. Move the hexagonal boron nitride flake to the selected clean region and engage the slide further downward **[1-TXT]**. ~~When the polycarbonate film and wafer are nearly in the same focal plane, reduce the speed to 5 micrometers per second **[2]**.~~

2.7.1. SCREEN: 68230_2.4-2.10.mp4 02:06-02:30 **TXT: Slide speed: 0.1 mm/s. Reduce to 5 µm/s when the polycarbonate film and wafer are nearly in the same focal plane**

~~2.7.2. SCOPE/SCREEN: Talent adjusting the speed and continuing to engage slowly.~~ **NOTE: Shot deleted by authors**

2.8. Now engage the stamp onto the wafer with a speed of 5 micrometers per second until it completely covers the hexagonal boron nitride flake **[1]**. Then set the sample stage temperature to 80 degrees Celsius **[2]**.

2.8.1. SCREEN: 68230_2.4-2.10.mp4 03:15-03:32.

2.8.2. Talent adjusting the stage temperature to 80 degrees Celsius.

2.9. After the sample stage temperature reaches 80 degrees Celsius, disengage the stamp with 5 micrometers per second until the wavefront is close to the hexagonal boron nitride straight edge then pick up the flake with a reduced speed of 2 micrometers per second **[1]**.

2.9.1. Shot of the sample stage temperature reaching 80 degrees Celsius
AND
SCREEN: 68230_2.4-2.10.mp4 04:02-05:00.
Video Editor: Please play both shots side by side

2.10. Once picked up, increase the speed to 5 micrometers per second to detach the polycarbonate film from the wafer **[1]**. Switch off the stage heater and open the water-cooling system **[2]**.

2.10.1. SCREEN: 68230_2.4-2.10.mp4 05:10-05:20.

2.10.2. Talent turning off the heater and turning on the water cooling system.

2.11. When the temperature drops below 45 degrees Celsius, close the water-cooling system **[1].** Disengage the glass slide all the way up at 1 millimeter per second **[2]**.

2.11.1. Talent closing the water-cooling system.

2.11.2. Shot of the glass slide being disengaged.

3. Picking up the Graphene Moiré Superlattice

3.1. Place the wafer with the freshly laser-cut graphene on the sample stage and locate the graphene using the 10X objective **[1]**. Adjust the flake orientation so the laser cutting lines are parallel to the hexagonal boron nitride straight edge **[2]**.

3.1.1. SCOPE/SCREEN: 68230_2.1-2.3_3.x.mp4 06:28-06:47.

3.1.2. SCOPE/SCREEN: 68230_2.1-2.3_3.x.mp4 06:47-07:01.

3.2. Outline the graphene boundary in Inkscape, including the laser-cutting lines **[1]**. ~~Use **Peek Through** to make the drawing semi-transparent while floating above the camera window **[2]**.~~

3.2.1. SCREEN: 68230_2.1-2.3_3.x.mp4 07:05
Video Editor: Please freeze frame here .

~~3.2.2. SCREEN: **Peek Through** is being used to make the drawing semi-transparent.~~
NOTE: Shot deleted by Authors

3.3. Now, move the glass slide with the top hexagonal boron nitride flake to the pre-engage position with the PC/PDMS stamp 2 millimeters above the graphene wafer **[1]**. Align the flake's straight edge with the center of the laser-cut line to match the hexagonal boron nitride with the graphene drawing **[2]**. Tune the microscope to focus on the graphene and align it to its Inkscape drawing **[3]**.

3.3.1. Shot of the glass slide being moved to the pre-engage position with the top flake above the wafer.

3.3.2. SCREEN: 68230_2.1-2.3_3.x.mp4 08:22-08:35 .

3.3.3. SCREEN: 68230_2.1-2.3_3.x.mp4 08:45-08:54.

3.4. Then, focus on the top flake and move the glass slide in XY *(X-Y)* direction to align it to its drawing **[1]**. After refocusing on a focal plane slightly higher than the pre-cut graphene, engage the glass slide downward at 0.1 millimeter per second until the top flake comes into focus **[2]**.

3.4.1. SCREEN: 68230_2.1-2.3_3.x.mp4 09:07-09:19.

3.4.2. SCREEN: 68230_2.1-2.3_3.x.mp4 09:38-09:55

3.5. Refocus on the graphene and set the speed to 5 micrometers per second **[1]**. Engage the stamp slowly until the flake becomes roughly visible while ensuring no contact with the wafer **[2-TXT]**. Continue to engage the stamp downward until it contacts the wafer **[3]**.

3.5.1. SCOPE/SCREEN: 68230_2.1-2.3_3.x.mp4 10:13-10:25

3.5.2. SCOPE/SCREEN: 68230_2.1-2.3_3.x.mp4 10:30-10:54. **TXT: Realign both the graphene and hBN to their drawings**

3.5.3. SCOPE/SCREEN: 68230_2.1-2.3_3.x.mp4 11:21-11:38.

3.6. Engage the stamp at 0.5 micrometers per second until the wavefront is close to the left edge of the flake **[1]**. Reduce the speed to 0.02 micrometers per second and continue engagement to contact the first graphene piece **[2]**.

3.6.1. SCOPE/SCREEN: 68230_2.1-2.3_3.x.mp4 11:47-12:09.

3.6.2. SCOPE/SCREEN: 68230_2.1-2.3_3.x.mp4 12:09-12:20,15:58-16:14 .

3.7. Once the flake fully covers the first graphene piece and is pinned at the straight edge, stop the engagement **[1]**. Clear hysteresis by moving the stage upward at 5 micrometers per second until the wavefront starts retracting **[2]**.

3.7.1. SCOPE/SCREEN: 68230_2.1-2.3_3.x.mp4 20:40-21:03

3.7.2. SCOPE/SCREEN: 68230_2.1-2.3_3.x.mp4 21:03-21:16

3.8. Set a disengaging speed of 0.02 micrometers per second to pick up the graphene gently **[1]**. When the wavefront moved away from the flake**,** increase the speed to 5 micrometers per second to fully detach the stamp from the wafer **[2]**.

3.8.1. SCOPE/SCREEN: 68230_2.1-2.3_3.x.mp4 21:22-21:45 .

3.8.2. SCOPE/SCREEN: 68230_2.1-2.3_3.x.mp4 41:07-41:32

3.9. Now copy the entire graphene drawing in Inkscape and rotate it by the desired twist angle **[1]**.

3.9.1. SCREEN: 68230_2.1-2.3_3.x.mp4 41:53-42:15
Video Editor: Please speed up the video .

3.10. Align the second graphene piece in the copied drawing with the first piece in the original drawing to maximize overlap **[1-TXT]**. Align the remaining graphene on the wafer to the copied drawing **[2]**.

3.10.1. SCREEN: 68230_2.1-2.3_3.x.mp4 42:25-42:38 **TXT: Rotate sample by desired twist angle** .

3.10.2. SCOPE/SCREEN: 68230_2.1-2.3_3.x.mp4 43:12-43:22.

3.11. Focus on the top hexagonal boron nitride flake on the glass slide and align it to the drawing **[1-TXT]**.

3.11.1. SCOPE/SCREEN: 68230_2.1-2.3_3.x.mp4 43:28-43:50 . **TXT: Examine quality of top stack under microscope then repeat steps with remaining graphene**

3.12. ~~After aligning the flakes to the drawings, repeat the demonstrated steps to pick up the remaining graphene **[1]**. Once picked up, examine the quality of top stack under microscope **[2]**.~~
NOTE: Step is a repetition of demonstrated procedure. It has been converted to on-screen text

~~3.12.1. SCOPE/SCREEN: 68230_2.1-2.3_3.x.mp4 44:42-1:12:03.~~

~~3.12.2. SCOPE/SCREEN68230_2.1-2.3_3.x.mp4 .~~

4. Encapsulation of the Graphene Moiré Superlattice

4.1. Place the wafer with the pre-cleaned bubble-free bottom gate on the sample stage **[1]**. Outline the boundary of the bottom gate using Inkscape **[2]**. Align the drawing of the top stack to that of the bottom gate to place the twisted bilayer graphene on the graphite finger **[3]**.

4.1.1. Talent positioning the wafer with bottom gate on the stage.

4.1.2. SCREEN: 68230_4.x.mp4 00:18-00:40, 01:12-01:17
Video Editor: Please speed up the video .

Added shot SCREEN: 68230_4.x.mp4 01:32-01:50

4.2. Set the sample stage temperature to 160 degrees Celsius to tear off the polycarbonate film after encapsulation **[1]**. Then load the glass slide with the top stack and move it to the pre-engage position **[2]**. Roughly align both the bottom gate and the top stack to the drawings **[3]**.

4.2.1. Talent setting the stage heater to 160 degrees Celsius.

4.2.2. Talent loading the glass slide with the top stack and moving it to the pre-engage position.

4.2.3. SCREEN: 68230_4.x.mp4 03:41-03:56, 04:02-04:12 .

4.3. Focus on the bottom gate, then slightly raise the focal plane **[1-TXT]**.

4.3.1. SCREEN: 68230_4.x.mp4 04:26-04:43 **TXT: Engage slide downward at 0.1 mm/s until top stack becomes visible**

4.4. Identify another middle focal plane between the bottom gate and top stack **[1]**. Then set the speed to 5 micrometers per second and engage the stamp until the top stack is visible **[2]**. Align both to the drawings accurately **[3-TXT]**.

4.4.1. SCREEN: 68230_4.x.mp4 05:03-05:08 .

4.4.2. SCREEN: 68230_4.x.mp4 05:09-05:49
Video Editor: Please speed up the video .

SCREEN: 68230_4.x.mp4 05:50-06:08 . **TXT: Repeat until bottom gate and top stack are almost in the same focal plane, and the sample stage temperature > 150 °C**

4.5. When the sample stage is above 150 degrees Celsius, engage the stamp at 5 micrometers per second until the wave front is close to the bottom gate, then reduce the speed to 0.5 micrometers per second **[1]**.

4.5.1. SCREEN: 68230_4.x.mp4 08:09-08:21.

4.6. Slowly engage the top stack onto the bottom gate **[1]**. Once the wavefront passes the top stack, increase the speed back to 5 micrometers per second to fully engage the stamp onto the wafer **[2-TXT]**. Then disengage the stamp at 5 micrometers per second **[3-TXT]**.

4.6.1. SCREEN: 68230_4.x.mp4 08:43-08:55.

4.6.2. SCREEN: 68230_4.x.mp4 09:07-09:40 **TXT: Wait for 1 min to soften PC film**

4.6.3. SCREEN: 68230_4.x.mp4 10:53-11:09. **TXT: The retracting wavefront denotes the detachment between the PC film and PDMS stamp**

4.7. After fully separating the stamp from the wafer, lift the stamp upward for 3 seconds at 5 micrometers per second **[1]**. Begin moving it in the X-Y directions to tear off the polycarbonate film **[2]**.

4.7.1. SCREEN: 68230_4.x.mp4 11:11-11:16

4.7.2. SCREEN: 68230_4.x.mp4 11:23-11:48.

4.8. Fully disengage the glass slide at 1 millimeter per second and remove it from the socket **[1]**. Switch off the stage heater and activate the water-cooling system **[2]**.

4.8.1. Talent lifting and removing glass slide.

4.8.2. Talent switching off heater and activating cooling.

4.9. Once the temperature drops to room temperature, remove the wafer and inspect under an optical microscope **[1]**.

4.9.1. Talent transferring the wafer to a microscope.

Results

5. Results

5.1. Four-fold degenerate Landau fans emerged from both the charge neutrality point and superlattice gaps in the high-quality magic-angle twisted bilayer graphene device **[1]**, breaking down into two-fold or one-fold degeneracies at higher magnetic fields **[2]**.

5.1.1. LAB MEDIA: Figure 8A. *Video editor: Highlight the symmetrical red-and-blue striped patterns radiating between 0 to 3*

5.1.2. LAB MEDIA: Figure 8A. *Video editor: please highlight the area of the graph at 3 and 4*

5.2. Symmetry-broken two-fold degenerate Landau fans were identified at half-filling states indicating correlated insulating behavior **[1]**. The superconducting dome was located underneath the Landau fan around the half-filling state **[2]**.

5.2.1. LAB MEDIA: Figure 8A. *Video editor: please highlight the area at ±2*

5.2.2. LAB MEDIA: Figure 8A. *Video editor: please highlight the low-field area at -2*

5.3. Temperature-dependent resistance measurements revealed two superconducting domes at both sides of the half-filling state with the maximum critical temperature reaching approximately 1.7 Kelvin **[1]**.

5.3.1. LAB MEDIA: Figure 8B. *Video editor: please highlight the dotted area*

5.4. Among 14 measured devices, the optimal critical temperature peaked at a twist angle near 1.08 degrees, consistent with theoretical predictions **[1]**.

5.4.1. LAB MEDIA: Figure 8C. *Video editor: Focus on the tallest data point in the plot*

5.5. Disordered devices near the magic angle exhibited significantly reduced critical temperatures compared to high-quality devices **[1]**, as seen in their resistance versus temperature profiles **[2]**.

5.5.1. LAB MEDIA: Figure 8C. *Video editor: Please highlight the two green data points*

5.5.2. LAB MEDIA: Figure 8D. *Video editor: Please highlight the orange and pink curves*

1. Pronunciation Guide:
   Moiré
   - Pronunciation link: https://www.merriam-webster.com/dictionary/moire
   - IPA: /mwɑːˈreɪ/
   - Phonetic Spelling: mwah-ray
2. **Superlattice**
   - Pronunciation link: https://www.howtopronounce.com/superlattice
   - IPA: /ˌsuː.pɚˈlæt.ɪs/
   - Phonetic Spelling: soo-per-lat-iss
3. **Graphene**
   - Pronunciation link: https://www.merriam-webster.com/dictionary/graphene
   - IPA: /ˈɡræˌfiːn/
   - Phonetic Spelling: gra-feen
4. **Heterostructure**
   - Pronunciation link: https://www.howtopronounce.com/heterostructure
   - IPA: /ˈhɛt̬.ə.roʊˌstrʌk.tʃɚ/
   - Phonetic Spelling: heh-tuh-roh-struhk-chur
5. **Twistronics**
   - Pronunciation link: https://www.howtopronounce.com/twistronics
   - IPA: /twɪsˈtrɑː.nɪks/
   - Phonetic Spelling: twis-trah-niks
6. **Hexagonal Boron Nitride**
   - Pronunciation links:
     - Hexagonal: https://www.merriam-webster.com/dictionary/hexagonal
     - Boron: https://www.merriam-webster.com/dictionary/boron
     - Nitride: https://www.merriam-webster.com/dictionary/nitride
   - IPA: /hɛkˈsæɡənl ˈbɔːrɑːn ˈnaɪˌtraɪd/
   - Phonetic Spelling: hek-sag-uh-nuhl bore-on nye-tride
7. **Polydimethylsiloxane (PDMS)**
   - Pronunciation link: https://www.howtopronounce.com/polydimethylsiloxane
   - IPA: /ˌpɑː.li.daɪˌmɛ.θəlˈsɪ.lɑːk.seɪn/
   - Phonetic Spelling: pah-lee-dye-meth-uhl-sih-lock-sayn
8. **Polycarbonate**
   - Pronunciation link: https://www.merriam-webster.com/dictionary/polycarbonate
   - IPA: /ˌpɑː.liˈkɑːr.bə.neɪt/
   - Phonetic Spelling: pah-lee-kar-buh-nayt
9. **Landau**
   - Pronunciation link: https://www.howtopronounce.com/landau
   - IPA: /ˈlæn.daʊ/
   - Phonetic Spelling: lan-dow
10. **Inkscape**
    - Pronunciation link: https://www.howtopronounce.com/inkscape

- IPA: /ˈɪŋk.skeɪp/
- Phonetic Spelling: ing-skayp

11. **Degenerate**
    - Pronunciation link: https://www.merriam-webster.com/dictionary/degenerate
    - IPA: /dɪˈdʒenərət/
    - Phonetic Spelling: dih-jen-uh-ruht
12. **Heterostrain**
    - Pronunciation link: No confirmed link found
    - IPA: /ˈhɛt̬.ə.roʊ.streɪn/
    - Phonetic Spelling: heh-tuh-roh-strayn
13. **Nanofabrication**
    - Pronunciation link: https://www.howtopronounce.com/nanofabrication
    - IPA: /ˌnæn.oʊˌfæb.rɪˈkeɪ.ʃən/
    - Phonetic Spelling: nan-oh-fab-ri-kay-shun
14. **Cryogenic**
    - Pronunciation link: https://www.merriam-webster.com/dictionary/cryogenic
    - IPA: /ˌkraɪ.oʊˈdʒɛn.ɪk/
    - Phonetic Spelling: kry-oh-jen-ik
15. **Superconductivity**
    - Pronunciation link: https://www.merriam-webster.com/dictionary/superconductivity
    - IPA: /ˌsuː.pɚ.kənˌdʌkˈtɪ.və.ti/
    - Phonetic Spelling: soo-per-kuhn-duhk-tiv-uh-tee