System for the Transfer of 2D Material

ME-314: Concurrent Engineering Project

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# Table of Contents

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Table of Contents</td>
<td>1</td>
</tr>
<tr>
<td>List of Figures</td>
<td>2</td>
</tr>
<tr>
<td>Introduction</td>
<td>3</td>
</tr>
<tr>
<td>Design Process</td>
<td>4</td>
</tr>
<tr>
<td>Next Steps</td>
<td>10</td>
</tr>
<tr>
<td>Conclusion</td>
<td>11</td>
</tr>
<tr>
<td>Appendix A - Parts List</td>
<td>12</td>
</tr>
<tr>
<td>Appendix B - Thorlabs’ Kinesis® Software</td>
<td>14</td>
</tr>
<tr>
<td>References</td>
<td>16</td>
</tr>
</tbody>
</table>
List of Figures

Figure 1: Stacking of 2D materials ........................................................................................................3
Figure 2: Transfer Process ....................................................................................................................3
Figure 3: Setup ......................................................................................................................................4
Figure 4: XYZ Micromanipulator and Components ...........................................................................5
Figure 5: XYZ Stage and Components .................................................................................................7
Figure 6: Microscope and Components ...............................................................................................8
Figure 7: Three Controllers Connected to The Hub ............................................................................9
Figure 8: Software Interface for Motors ...............................................................................................14
Figure 9: Loading a Cube .....................................................................................................................14
Figure 10: Unloading a Cube ..................................................................................................................15
Figure 11: Setting the Step Amount .....................................................................................................15
Introduction

Stacking sheets of different two dimensional crystals (as shown in Figure 1) can create structures with useful properties for applications in batteries, semiconductors and other devices.

![Figure 1 - Stacking of 2D materials](image)

However, current methods for creating these structures tend to be inefficient and difficult. A paper from Delft University entitled “Deterministic transfer of two-dimensional materials by all-dry viscoelastic stamping” proposes an all-dry transfer method that has a yield rate close to 100% [2]. The transfer process as described in the paper is summarized below in Figure 2.

![Figure 2 - Transfer Process](image)

Project Motivation

The goal was to create a setup that uses an all-dry transfer method to stack two-dimensional crystals, similar to the one seen in the paper by Delft University. However, in addition to the setup shown in the paper, there were a few major additions:

1) A heating element and resistance thermometer (RTD) were added below where the target substrate sits, as 2D layers of certain materials bond better at higher temperatures [3].

2) The glass slide carrying the stamp can be tilted when being applied to the target material, as it is (indirectly) attached to a goniometer.
3) A force sensor to measure the force applied by the glass slide to the target material. This allows users to control the angle of contact between the two as well as the force applied, which could potentially improve the quality of the material produced.

Design Process

The first step in creating this setup was creating a schematic in SolidWorks with all the necessary parts. All parts were bought from Thorlabs unless otherwise stated. A SolidWorks rendering of the setup is shown below in Figure 2. The components holding up the microscope, the controllers, and the breadboard (B3045AE) are not shown.

Figure 3 - Setup

The setup can be divided into three main elements, all of which are described below.
XYZ Micromanipulator

The primary purpose of the XYZ micromanipulator and the components connected to it is to position the glass slide in the XY plane, and then move it downwards to bring the stamp into contact with the substrate material placed on the sample stage. As the flakes of 2D materials involved are very small, the user must be able to manipulate the samples with a great deal of precision. It is especially important that control of the Z-axis movement during the stamping process be extremely precise, more so than in the X or Y directions. This allows the user to apply the exact amount of force required when bringing the viscoelastic stamp into contact with the substrate material. Secondary objectives accomplished by this portion of the setup are to adjust the angle at which the stamp comes into contact with the substrate material, and to measure the downwards force applied by the glass slide to the sample stage.

As the system is based off of the one described in the Delft paper, the same XYZ Micromanipulator from Thorlabs was selected to be used as the base for the entire micromanipulator structure. The micromanipulator selected (RB13M/M) offers sufficient precision and accuracy in movement along all 3 axes, and had already been successfully used in a nearly identical application by the researchers at DTU. Furthermore, the manual controls for each axis can be easily replaced with motor actuators, which allows for greater precision and smaller step sizes than can be achieved manually. Since precise control of the Z-axis (vertical) movement is especially important, a motor actuator (ZST213B) was used in place of the manual barrel control. For the X and Y axes, the precision offered by the manual controls was considered to be sufficient.
While the micromanipulator selected can move the slide in all 3 directions, it cannot satisfy the secondary objective of adjusting the pitch and roll of the slide. To accomplish this function, a tilt platform, or goniometer, was placed on top of the micromanipulator stage. The goniometer stage could then be moved in all 3 directions and the pitch and roll of the stage adjusted as desired. The criteria considered in selecting a goniometer were adjustment range and load capacity. The model chosen (GNL20/M) was the only one offered by Thorlabs that allowed the stage to be locked in place at the desired pitch and roll, allowing it to support a higher load and preventing it from unintentionally shifting during the transfer process. Additionally, it offered a greater range of rotation (+/- 10°, 15°) than most other Thorlabs products. There was, however, some difficulty in connecting it to the micromanipulator stage. The placement of screw holes on the standard micromanipulator top plate did not match up with those on the bottom of the goniometer, requiring the standard top plate to be replaced with a special adapter plate (RB13P1/M).

To evaluate the applied force in the vertical direction during the transfer process, multiple options were considered. These included measuring the deformation of the glass slide with a strain gauge and computing the force from this result, and placing a force sensor beneath the heating element on the sample stage. The disadvantage of the strain gauge compared to a force sensor is that it would have added a layer of complexity and had a greater potential for error since the final result would have to be calculated based on its readings. As the sample stage is heated during the transfer process, a force sensor positioned somewhere beneath it may have produced inaccurate results from being exposed to high temperatures. A traditional force sensor incorporated into the micromanipulator structure was therefore the optimal solution. Unfortunately, the only compatible force sensor offered by Thorlabs (FSC103/M) does not detect forces acting perpendicular to the surface of its platform, but rather parallel to it. This required the force sensor to be placed such that its top platform is at a 90° angle to those of the micromanipulator and goniometer. To do so, an L-bracket was required to connect the top of the goniometer stage and the bottom surface of the force sensor, with a 90° angle between the two. None of the L-brackets offered by Thorlabs met these requirements, so a custom L-bracket was designed instead. Making this difficult was the design of the underside of the force sensor, which had no screw holes but merely a ridge down its center meant to slide into a corresponding groove on a platform. Connecting the force sensor using this groove system was considered in an early design, however it would have been difficult to manufacture and not very secure. Instead, the screws holding together the underside of the force sensor were removed (after verifying it was safe to do so with Thorlabs technical support) and the L-bracket connected by screws passing through these holes. Once the compatibility of the L-bracket with all other components was verified in the SolidWorks model, it was manufactured in the EPFL machine shop.

The final component of the structure, the slide holder, would then be secured to the top platform of the force sensor. An existing design by Tom Larsen was modified so that it could be secured to the surface of the force sensor, and was then 3D printed at EPFL. Slides are inserted into the slot in the slide holder, and then clamped in place by tightening 2 bolts passing through the slot. As the slide is the part carrying the viscoelastic stamp, it is very important that it
be securely clamped and all other components in the structure held securely in place to allow the user the greatest level of precision possible.

**XY θ stage**

![Figure 5 - XY θ Stage and Components](image)

The primary purpose of the XY θ stage and the attached components is to have finer control over the sample stage, rather than just relying on the XYZ micromanipulator movement. The secondary objectives were to be able to heat up the sample stage, and be able to control the temperature through the use of an RTD and a controller.

This is the same stage (XYR1/M) that the Delft paper used as well. The Delft setup has a large metal cylinder base on which the sample sits on. In contrast, this setup has a clamping base (BA2F/M) on top of the stage, to which a post (RS50/M) is attached. A horizontal platform sits on top of this post, which is is an adjustable flip platform (FP90/M). It was chosen because it was the only horizontal platform sold by Thorlabs that could sit on top of the post. It is currently locked in this position, but it is possible for it to be on an angle. This was seen as a cheaper alternative than manufacturing the metal base, and would be faster to get since both parts are sold by Thorlabs instead of needing to ask the machine shop to manufacture it.

The metal ceramic heating element (HT24S) sits on top. Originally, a peltier element was going to be used, but this was changed to a ceramic heater since it was not necessary to cool the sample, and the ceramic heater can reach higher temperatures. This heating element was added because certain materials bond better at higher temperatures.
Finally, a manufactured copper block, with a hole in which the RTD sensor (part number 615-1043-ND on Digi-Key) can fit, sits on top of the heating element. The purpose of the RTD is so that it is possible to control the temperature of the heating element with the use of a controller.

**Microscope**

![Microscope and Components](image)

Figure 6 - Microscope and Components

The primary purpose of the microscope and the components connected to it is to be able to select the appropriate thin flakes of material, and aid in aligning the glass slide (which holds the thin flake) to the substrate material. This is an incredibly important part of the process since looking through the flakes of the material and identifying an appropriate one to use is one of the most time consuming processes. Furthermore, aligning it on top of the substrate material is important since the desired results may not be achieved if they are not perfectly aligned.

It is important to note that in this schematic, the camera attached to the microscope is not shown. It attaches to the top of the microscope. It can be connected to a computer and using the UEye Cockpit program, it is possible to see through the microscope. The microscope and the camera were already in the lab, while the the objective lens (MY10X-803) was purchased.

In the Delft paper, a rack & pinion mechanism is used to hold the microscope and move it up and down. This was not used in this design, since their rack & pinion mechanism was sold by another company and Thorlabs did not have any equivalent mechanism. In this setup, a 1.5in post (P350/M) is attached to a base adapter (PB4/M), which is then attached to the breadboard with a clamping fork (PF175). This post was selected since it would be sturdy enough to support the microscope without being too bulky. The base adapter is necessary so that the post can be
used with the clamping fork. The clamping fork can be screwed through to attach the post to the breadboard.

Attached to the pole is a mounting clamp (C1511/M), which allows for rough positioning of the microscope, as it can easily be loosened and tightened up and down the pole. This was initially going to be used to replace the rack & pinion, but having to repeatedly loosen and tighten it to get the microscope where necessary was inconvenient. Thus, a motorized linear stage (PT1/M-Z8) was attached to the mounting clamp. The mounting clamp would allow for rough positioning, while the motorized stage would allow for more precise positioning of the microscope to help focus the image.

Finally, the adapter plate (provided by Tom Larsen) attaches to the stage, since the ring clamp could not fit on the stage directly. The microscope was then put through the ring clamp, by unscrewing one part of the microscope, putting the microscope through the hole, and then screwing the part back in.

Controllers

![Three Controllers Connected to The Hub](image)

Figure 7 - Three Controllers Connected to The Hub

The controllers were not shown in the schematic, and will be explained in detail below. There are three controllers in total in this set up - one for the motorized linear stage (KDC101), one for the motor controlling the Z-direction of the XYZ micromanipulator (KST101), and a strain gauge reader for the force sensor (KSG101). These controllers all connect to one magnetic hub (KCH301), which can be attached to the breadboard. The advantage of having one hub is that it uses a single USB cord to connect to a computer. Otherwise, each controller would require a different USB cord. After the hub is connected to a computer, software can be used to control each of the components.

The primary objective of the controllers for the 2 motors was to be able to move the motors by a set step amount, up and down. Thorlabs' Kinesis® software is sufficient to satisfy this objective. However, if more complicated features are needed in the future, the Kinesis® software can be integrated with LabVIEW. For more information on how to use Thorlabs' Kinesis® software for the three controllers, refer to Appendix B.

A summary of all the parts used, the part number, and its function, can be found in Appendix A.
Next Steps

At this stage in the project all of the parts have been either delivered or manufactured, and the majority of the system has been assembled. The two motors and the force sensor have all been installed and tested.

Once the assembly is completed, the next major step is testing the system by trying to create 2D material structures. Depending on the results of the testing it may be necessary to make some modifications, however assuming that the tests are successful, the next step would be to add new features and improve upon existing ones.

There have been some issues with the temperature controller that will need to be resolved. The controller displays the error “TEC open” and stops functioning whenever the current surpasses 0.35A, which is necessary to reach the desired temperature of 110°C. When controlled by a Matlab script and with an additional power source connected, high temperatures can still be achieved but only because the Matlab script constantly turns the controller back on immediately after the “TEC open” error shuts it off. This was not tested very much because of concern that it would damage the controller.

One idea would be to automate the control of the Z-axis movement on the micromanipulator based on feedback from the force sensor. If the user knew how much force should be applied during the transfer process, the motor controlling Z-axis movement could be programmed to slowly move the slide downwards until the force sensor detects the desired magnitude of force. The programming could potentially be done in LabVIEW, Matlab, or perhaps some other program if it proves to be too complicated for either of those. The benefit of this feature is that it allows the user to be very precise in how much force is applied between specimens of 2D materials, should that be an important factor in their procedure.

A potential issue that may be worth investigating during the testing phase is that if the slide is tilted in any orientation by the goniometer, it will likely cause the reading from the force sensor to be incorrect. Since the force sensor only detects forces perpendicular to the plane of the slide, if the slide were at an angle to the sample stage the force sensor would not be reading the force applied along the Z axis. One way of solving this problem might be to put the force sensor beneath the sample stage instead, and find some way of insulating it from the heating element.

Another possible improvement to the system would be to replace the manual controls on the micromanipulator for the X and Y axes with motors, as was done for the Z direction. If observations during testing indicate that it is difficult to precisely position the slide in the XY plane with manual controls, then this would be a potential solution.
Conclusion

Likely the greatest challenge in this project was trying to find components offered by Thorlabs that both met the design requirements and were compatible with one another. Thorlabs offers many parts that are designed to work with certain other parts and accessories, often for specific purposes. However, in creating this system some parts had to be used in situations and with other parts for which they were not specifically designed. For example, an L-bracket had to be custom manufactured to connect the goniometer to the force sensor. It was therefore very important to carefully check the specifications of each part (e.g. load capacity, travel range) and understand their limits of operation, something which sometimes involved contacting Thorlabs technical support staff. A SolidWorks assembly including each component was created before ordering any parts, which was an excellent tool to confirm that all of the components would fit together as intended and for designing the parts that had to be manufactured.

The major goal of this project was to design and build a setup capable of creating 2D materials. Pending a final test, this goal has been accomplished, and 2D materials can now be created using the system. Depending on the test results, the setup may need to be modified in some way. Otherwise, new features could be added to further improve the system.
## Appendix A - Parts List

<table>
<thead>
<tr>
<th>Component</th>
<th>Part Number</th>
<th>Supplier</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>RTD Sensor</td>
<td>615-1043-ND</td>
<td>Digi-Key</td>
<td>Sensing temperature of stage surface</td>
</tr>
<tr>
<td>Breadboard</td>
<td>B3045AE</td>
<td>Thorlabs</td>
<td>Breadboard</td>
</tr>
<tr>
<td>Base for post</td>
<td>BA2F/M</td>
<td>Thorlabs</td>
<td>Base for post holding up specimen platform</td>
</tr>
<tr>
<td>Adjustable Flip Platform</td>
<td>FP90/M</td>
<td>Thorlabs</td>
<td>Platform for supporting specimen platform</td>
</tr>
<tr>
<td>Post for microscope</td>
<td>C1511/M</td>
<td>Thorlabs</td>
<td>Replacement for rack and pinion clamp, has quick release handle but no adjustment knobs</td>
</tr>
<tr>
<td>Force Sensor</td>
<td>FSC103/M</td>
<td>Thorlabs</td>
<td>Force sensor for measuring force applied to specimen</td>
</tr>
<tr>
<td>Goniometer</td>
<td>GNL20/M</td>
<td>Thorlabs</td>
<td>Tilt platform</td>
</tr>
<tr>
<td>Controller Hub</td>
<td>KCH301</td>
<td>Thorlabs</td>
<td>Mounting unit for K-Cube controllers. Allows all 3 to connect to a computer via a single USB cable, and all 3 to share a single power supply</td>
</tr>
<tr>
<td>Controller for motorized stage</td>
<td>KDC101</td>
<td>Thorlabs</td>
<td>Controller for the single axis translation stage on microscope holder (MT1/M-Z8)</td>
</tr>
<tr>
<td>Strain Gauge Reader</td>
<td>KSG101</td>
<td>Thorlabs</td>
<td>Strain gauge reader</td>
</tr>
<tr>
<td>Component</td>
<td>Model</td>
<td>Manufacturer</td>
<td>Description</td>
</tr>
<tr>
<td>-----------------------------</td>
<td>-------------</td>
<td>--------------</td>
<td>------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Motor Controller</td>
<td>KST101</td>
<td>Thorlabs</td>
<td>Controller for a single motor actuator - 1 required per motor</td>
</tr>
<tr>
<td>Motorized Linear Stage</td>
<td>PT1/M-Z8</td>
<td>Thorlabs</td>
<td>Motorized stage, for fine adjustment of microscope height</td>
</tr>
<tr>
<td>Objective Lens</td>
<td>MY10X-803</td>
<td>Thorlabs</td>
<td>Objective lens for microscope</td>
</tr>
<tr>
<td>Post for microscope</td>
<td>P350/M</td>
<td>Thorlabs</td>
<td>Thorlabs optical post, replacing rack and pinion style of Edmund Optics post</td>
</tr>
<tr>
<td>Adapter base for post</td>
<td>PB4/M</td>
<td>Thorlabs</td>
<td>Base for optical post, allows it to connect to clamping fork</td>
</tr>
<tr>
<td>Clamping Fork</td>
<td>PF175</td>
<td>Thorlabs</td>
<td>Secures optical post and the post base to the breadboard</td>
</tr>
<tr>
<td>XYZ Micromanipulator</td>
<td>RB13M/M</td>
<td>Thorlabs</td>
<td>Micromanipulator that moves slides</td>
</tr>
<tr>
<td>Adapter Plate</td>
<td>RB13P1/M</td>
<td>Thorlabs</td>
<td>Adapter plate for Goniometer</td>
</tr>
<tr>
<td>Sample Stage Post</td>
<td>RS50/M</td>
<td>Thorlabs</td>
<td>Post holding up specimen platform</td>
</tr>
<tr>
<td>XY ( \theta ) Stage</td>
<td>XYR1/M</td>
<td>Thorlabs</td>
<td>Stage that rotates and travels in x-y direction</td>
</tr>
<tr>
<td>Ceramic Heater</td>
<td>HT24S</td>
<td>Thorlabs</td>
<td>Heating element</td>
</tr>
<tr>
<td>Motor Actuator</td>
<td>ZST213B</td>
<td>Thorlabs</td>
<td>Motorized adjustment of xyz stage - replaces manual barrels can be removed and replaced</td>
</tr>
</tbody>
</table>
Appendix B - Thorlabs’ Kinesis® Software

The software used to control the motors and to read from the force sensor is Thorlabs’ Kinesis® software, and only works on the Windows platform. It provides built-in functionality to work with the motors, and can be integrated with other software programs like LabVIEW for custom controls. However, for basic functionality, such as moving the motors by a certain step amount, the built-in software works.

To begin, ensure that the controller hub is connected to the power supply, the cubes are turned on and a USB cable is connected from the hub to the computer. Then, open up the Kinesis software. The interface is shown in Figure 8 below.

![Figure 8 - Software Interface for Motors](image)

As can be seen, all the controllers connected are shown automatically when you start the application. If a controller is connected to the USB hub after the application startup, it is possible to load it, as shown in Figure 10. It is also possible to unload it, as seen in Figure 11.

![Figure 9 - Loading a Cube](image)
Finally, to set the step size amount, click the 'Jog' button, and the step size amount can be set from there, as seen in Figure 11. After clicking 'Apply', clicking the up or down arrow buttons will move the motor.

This is the most basic functionality, but things like acceleration, velocity, etc, can be set from this interface as well.
References

