# Robotic cell assembly to accelerate battery research

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**Supplementary Information**

Shown in Figure S1 are false color images of XRF peak intensities measured on a 5 cm by 5 cm large anode electrode sheet as used in this study. As is visible in the images the Si-signal distribution is inhomogeneous across the film. As reference the Cu foil signal is shown.

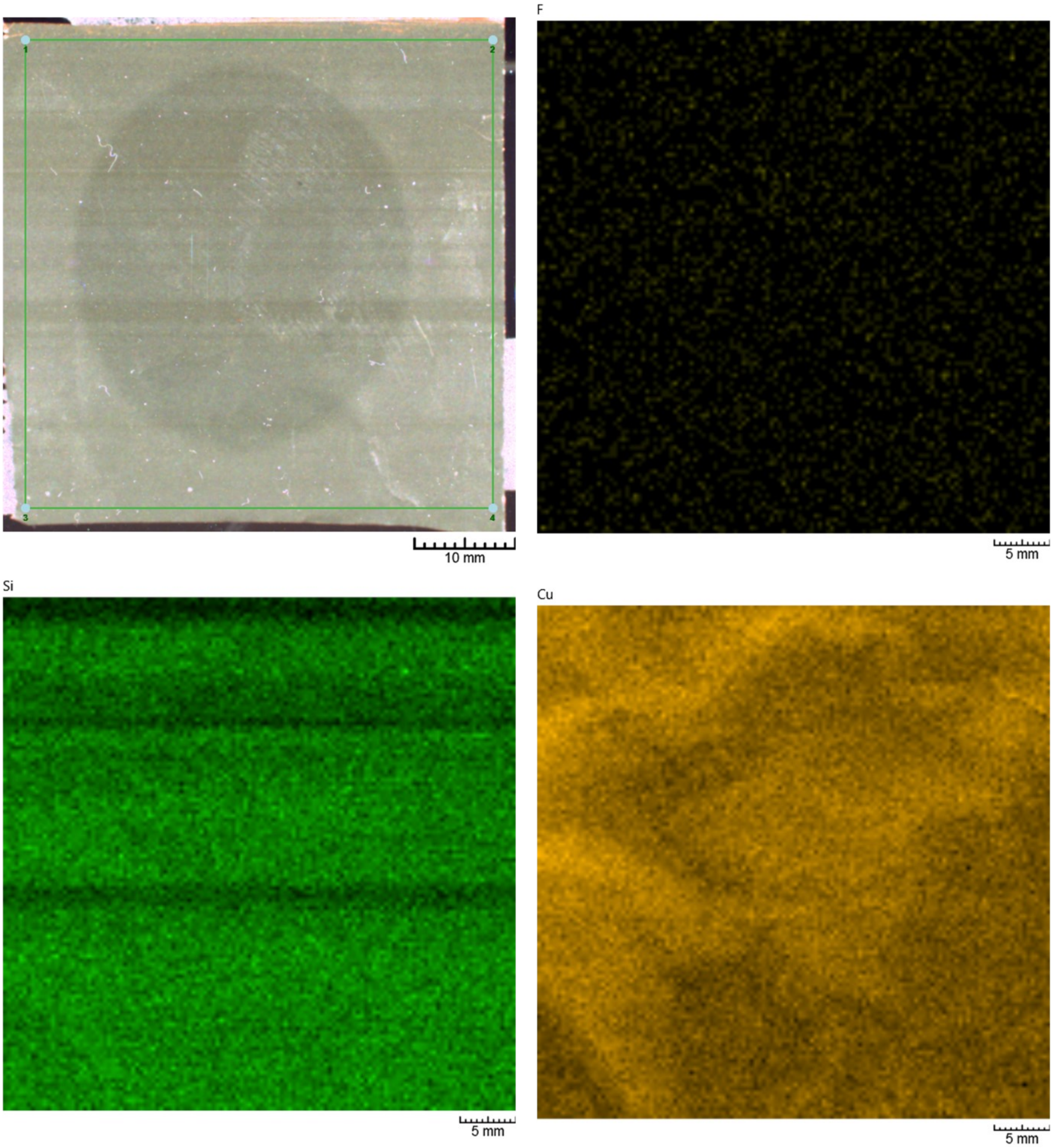



Figure S1: Inhomogeneities in Si over a 5 cm by 5 cm electrode. The first panel shows a picture with the area marked where the mapping is performed. The color in the other images roughly translates to the amount of material detected via XRF. The F and Cu signal are shown as reference for height variation and to assess binder dispersion in comparison to Si-particle dispersion

## Robotic CR2023 Assembly

The following text contains a detailed description with photos of all steps during automatic cell assembly

**Cell Construction**

The AUTOBASS is specifically designed for manufacturing the test cells in the standard form of CR2032 coin cells which are designed in the dimension of 20 mm in diameter and 3.2 mm in thickness. Each cell contains two SS304 spacers of 0.5 mm thick and 15.5 mm in diameter and one conically shaped spring of 1.2 mm in height and 15.4 mm in diameter. The outer cases of the coin cell are composed of a 20 mm diameter positive case made of SS304 and a 19.8 mm diameter negative case of SS304 with an O-ring which is placed in electric contact with the spring and the spacer beneath the anode, respectively. An asymmetric cell design is implemented, in which a larger anode size (15mm in diameter) is used as the cathode (15 mm in diameter) and in between is a 16 mm diameter separator.

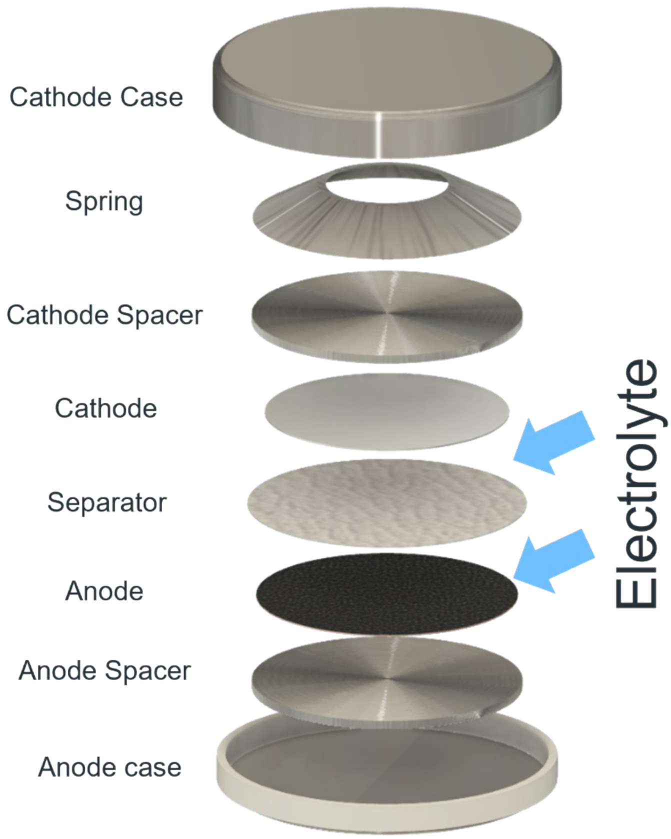



***Figure S2:*** *Schematic rendering of the CR2032 Cell construction.*

**Assembly Preparation**

To accommodate the assembly procedure of the cell CR2032 construction, 7 trays, each with 64 pitches (shown in Figure 1) in different diameters according to components' sizes were designed. All components including the pre-cut electrodes and separators need to be manually loaded into the pitches of trays accordingly, due to the identical size of the two spacers, the cathode and anode spacers are stack placed into the same pitch. Prior to starting the assembly, first the system needs to go through a series of initiating and checking progress in sequence: the two robotic arms and the linear rail need to be activated and homed, other instruments such as the syringe pump and microcontrollers will need to run connection and configuration check. This can be done automatically by following the steps guided in our graphic user interface. After that, the system is all set and ready to assemble coin cells.

**Assembly procedure**

The automatic assembly procedure is coordinated according to the standard procedure of manual coin cell assembly guidelines and others recommended by BIG-MAP. The assembly started with the anode case facing downwards, then come to the handling of different components in sequence, which are: first spacer placement, anode placement, first electrolyte dispensing, separator placement, second electrolyte dispensing, cathode placement, second spacer placement, spring placement, and closing with cathode case, then in the end, to the final steps as sealing and finishing up. Each step will be detailly described in the next context.

**Anode case placement**

The linear rail will first drive Robot A (the assembly robot) to the place next to the tray of the anode case, the vacuum gripper mounted on robot A will then reach down and grab the anode case with vacuum, with the anode case being vacuum grabbed, the robot arm zeroes all its joints and the linear rail jogs robot A to the nearby of the assembly post, the anode case goes down with the suction cup into the pitch of the assembly post and was placed on to it upon releasing of the vacuum (Figure 3).

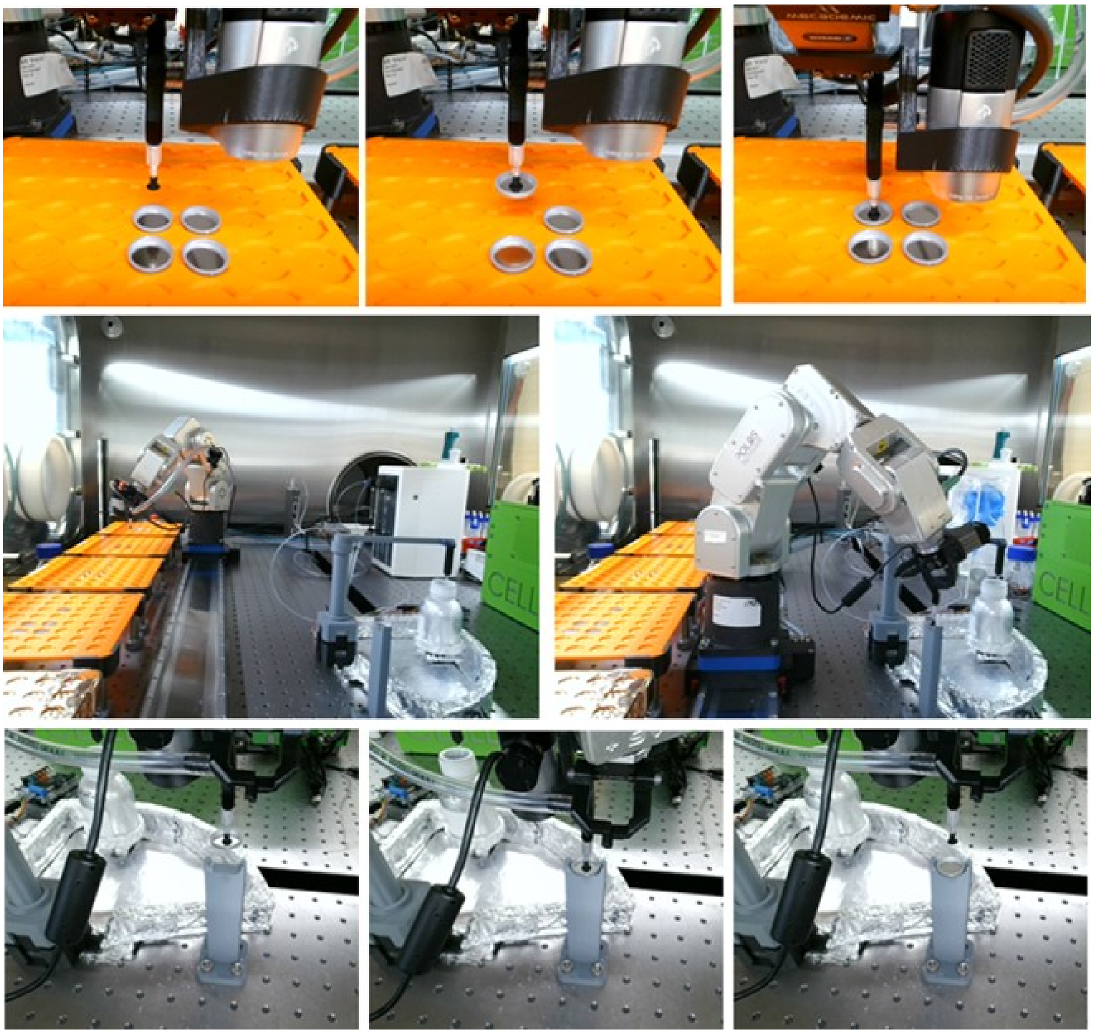


***Figure S3:*** *Anode case being vacuum grabbed, transported, and placed onto the assembly post*

**Anode spacer placement**

Similar to that of the anode case, the first spacer will be picked up from its tray and placed in the middle the anode case placed on the post earlier (Figure 4).

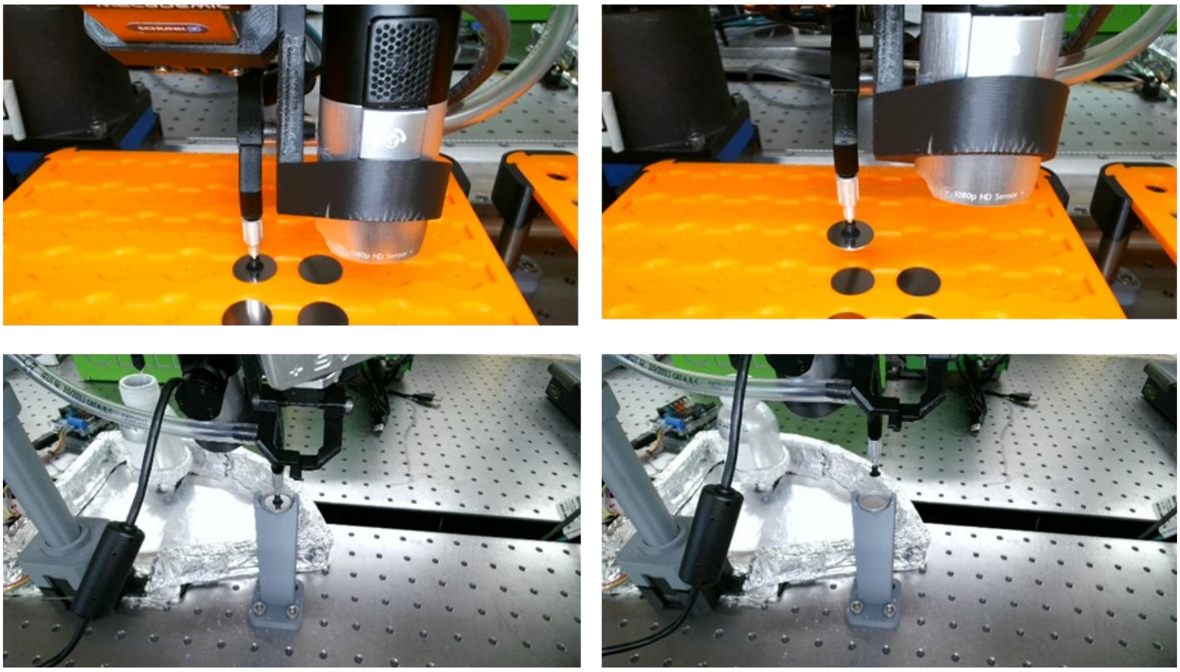


***Figure S4:*** *Anode spacer being vacuum grabbed, transported, and placed on the anode case*

**Anode placement + First electrolyte dispensing**

The 15 mm anode sheet will be vacuum grabbed in the same way as the anode spacer, and placed onto the top of the first spacer with its copper foil side facing downwards. The robot then moves up aside, pointing the amounted camera right above the anode, takes a picture, and return to the homing position. Upon the anode placement, the first portion of electrolyte will be injected onto the anode's active material surface. During this step, driven by a stepper motor connected underneath, a tap-like arm made of a PTFE 3D-printed hose will rotate in the direction of the assembly post, pointing the piping tip buried inside of the hose to the anode from last step. Through a computer-controlled syringe pump, 15.7 µL electrolyte will be pumped from its container through the pipeline to the anode's surface. Upon finishing the arm rotates in the opposite direction and back to its initial position (Figure 5).

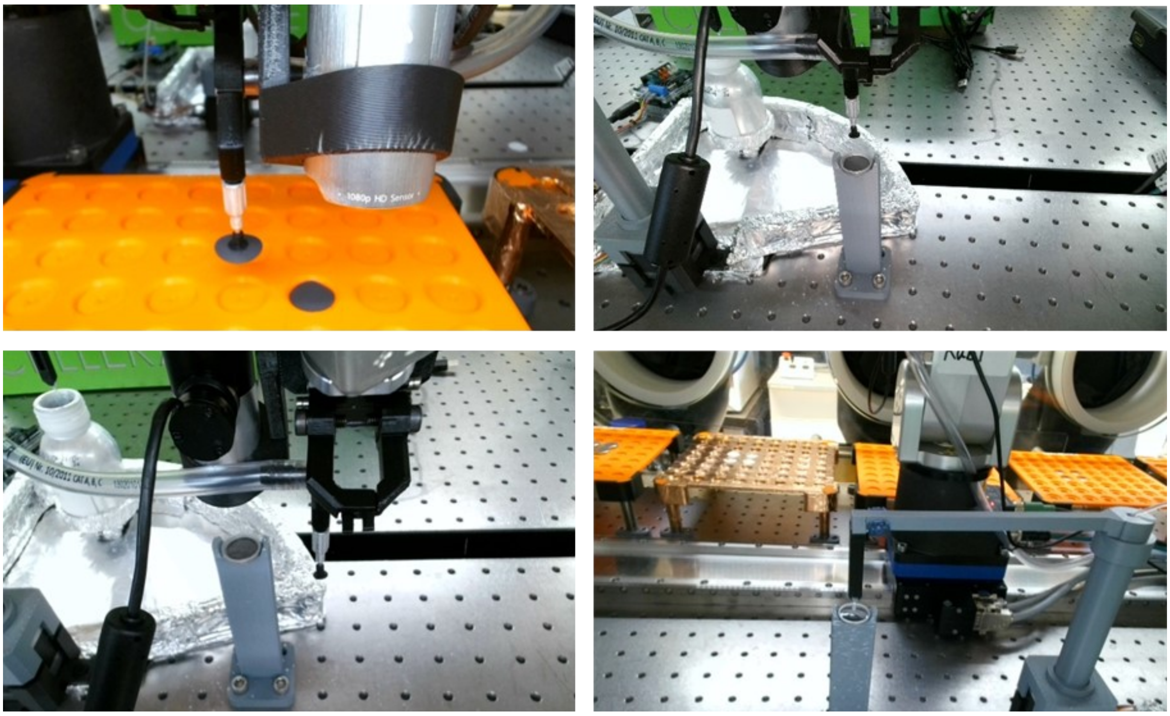


***Figure S5:*** *Anode being placed on top of the anode spacer, got photoed and dispensed with electrolyte on the surface.*

**Separator placement + Second electrolyte dispensing**

The 16mm separators are initially held in a copper foil-wrapped tray and with its metallic parts grounded, proposing to compensate for the issue of static charging. The separator is vacuum gripped and moved above the anode with electrolyte on the surface, with the vacuum gripper moving downwards, the separator is then pressed against the anode, under the effect of surface tension and adhesion from the electrolyte, the separator is then in adhesion to the anode. As the last step, another picture is taken to show how well the separator is aligned. Upon the separator placement, the second portion of electrolyte is injected onto the separator in the same manner as the one during anode’s assembly (Figure 6).

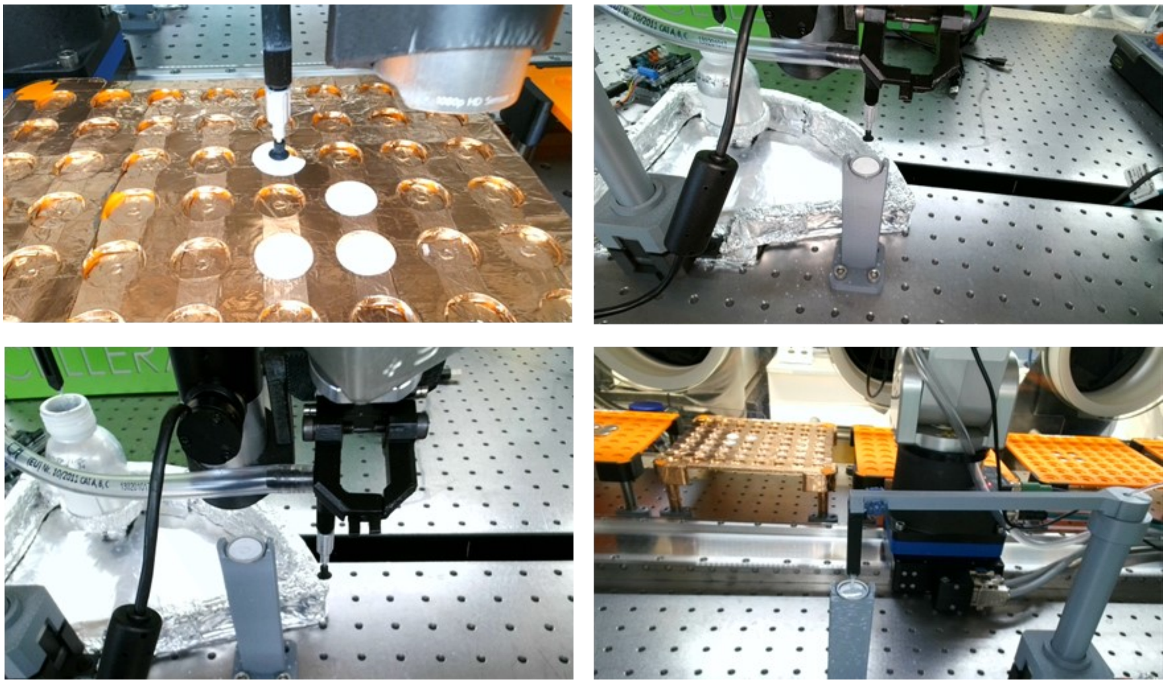


***Figure S6:*** *Separator being placed on top of the anode, got photoed and dispensed with electrolyte on the surface.*

**Cathode placement**

The 14 mm cathode is vacuum-grabbed on its aluminum surface and pressed against the separator wetted with electrolyte. Same to the anode and the separator, another picture is taken from the identical position for the post-analysis (Figure 7).

***Figure S7:*** *Cathode being placed on top of the electrolyte-wetted separator and got photoed.*

**Cathode spacer placement**

A second spacer (cathode spacer) is serving as the electrical contact with the cathode, in the meanwhile contributing to increasing the mechanical tension inside of the cell, the assembly is similar to that of the first spacer, as the spacers are stack placed prior to the assembly, it will be picked up from the same pitch as the first one and placed on top of the cathode (Figure 8).

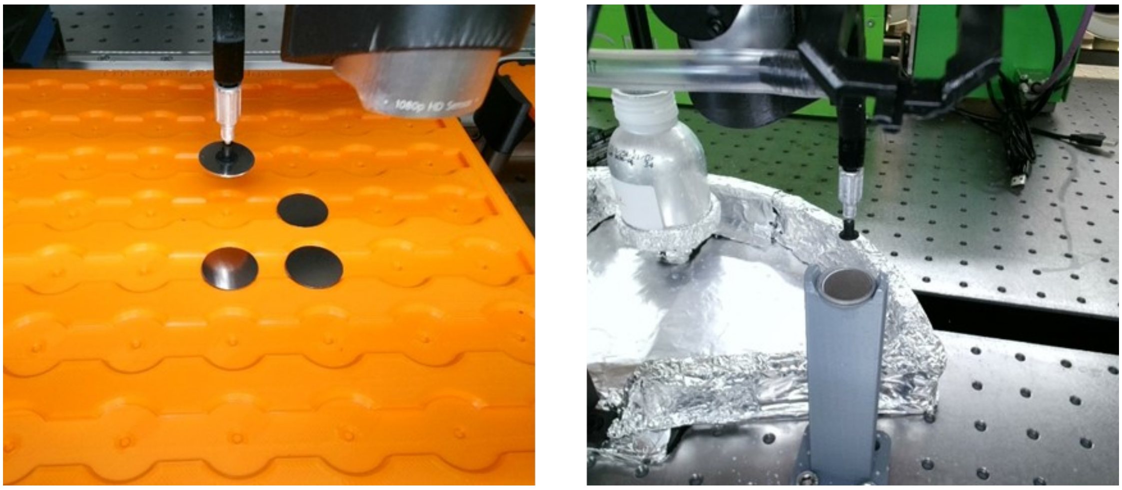


***Figure S8:*** *Cathode spacer being vacuum grabbed, transported, and placed on top of the cathode.*

**Spring placement**

Due to the special conical shape, the 15.4 mm conical spring will be picked up using a gripper, the self-rectifying inside gripping mold on gripper A beneath the vacuum gripper (Figure 1, 4a) is therefore designed to grab the spring from its inside hole. Again, the linear rail jogs the robot to the nearby of spring tray, gripper goes low enough to place itself in the middle of the hole of the conical spring, then grab the spring by opening the gripper. The gripper again goes up and linear rail jogs Robot A to the place next to the assembly post, the spring will end sitting on top of the second spacer, providing sufficient mechanical stress between the components after sealing (Figure 9).

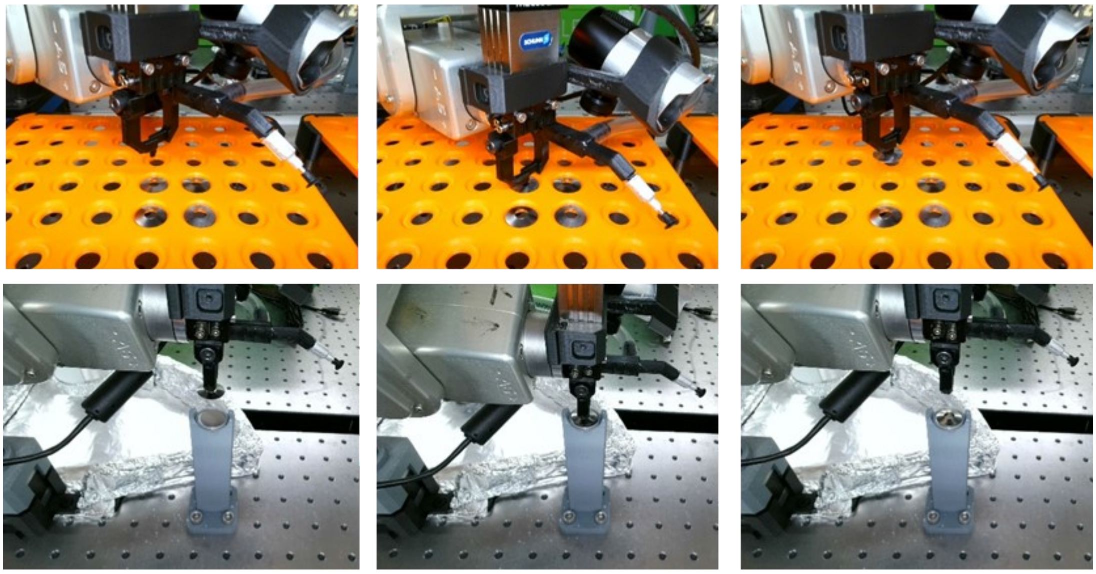


***Figure S9:*** *Conical spring being grabbed by gripper from its inside hole, placed on top of the cathode spacer.*

**Closing with cathode case**

As the last component, the 20 mm cathode case will be picked up by using the vacuum gripper and transported above the rest of the components on the assembly post. Due to the larger size, the cathode case will enclose all the components in between with the anode case. The cell will then be closed as the case goes down with the suction cup (Figure 10).

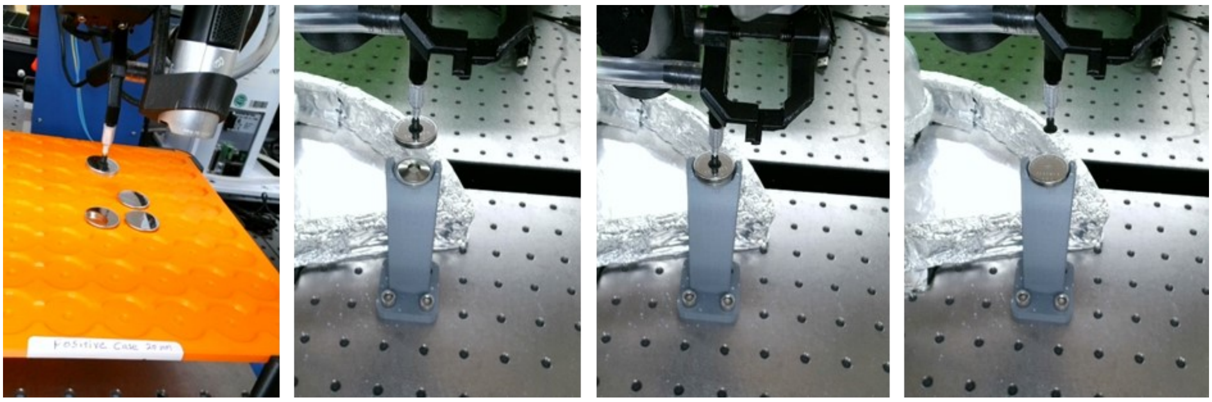


***Figure S10:*** *Cathode case being vacuum grabbed and pressed against the rest component to close the cell.*

**Sealing**

Transporting of the assembled cell from the assembly post to the crimper will be needed before sealing. Therefore, robot B picks up and flips the closed cell with gripper B to transfer it to the crimper. The crimper (MTI MSK-160E, China) is then being triggered by a microcontroller-connected relay to start the crimping procedure. The pressure is set through an analog dial to 800 kg. After the crimping tool reverts to its homing position, robot B approaches the crimper again to pick up the finished cell from the die through a magnetic gripping mold on top of its gripper (see Figure 1) finger to transfer it to the assembly post. By performing a sliding movement on top of the assembly post, the cell is dropped in the assembly post with the cathode cup facing up (Figure 11).

***Figure S11:*** *Closed cell is transported by Robot B to the die of the crimper, get crimped and then placed back onto the assembly post.*

**Finishing up**

Upon sealing, robot A picks up the cell, then jogs to the cathode case tray and places the finished cell into the vacant position where the corresponding cathode cup which was previously used to close the cell (Figure 12).

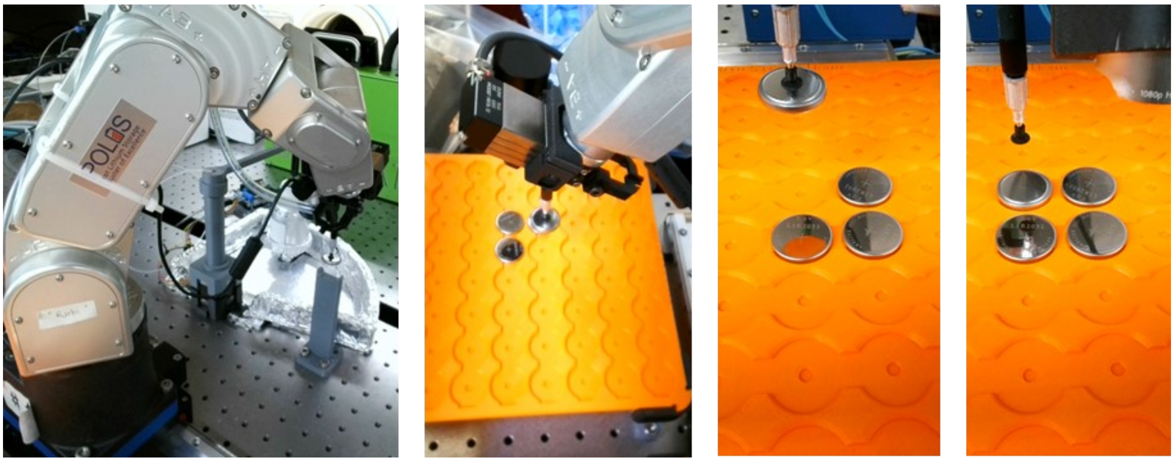


***Figure S12:*** *Finished Cell is relocated to the cathode case tray.*

## Software Operation

This guidance is intended to instruct users of AutoBASS on how to properly install module dependencies and start assembly cells with the help of AutoBASS GUI.

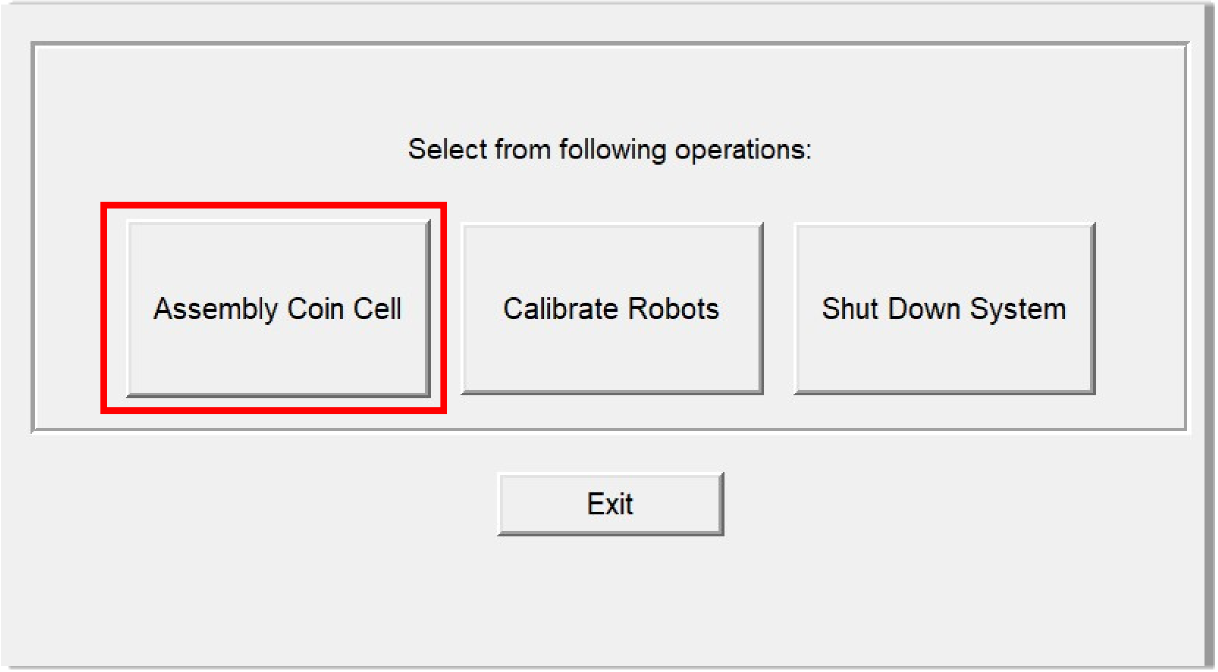
1. Installing environmental dependencies:

    1.1. AutoBASS runs under python 3.7 or a later version, please make sure that you've installed the correct version of python.

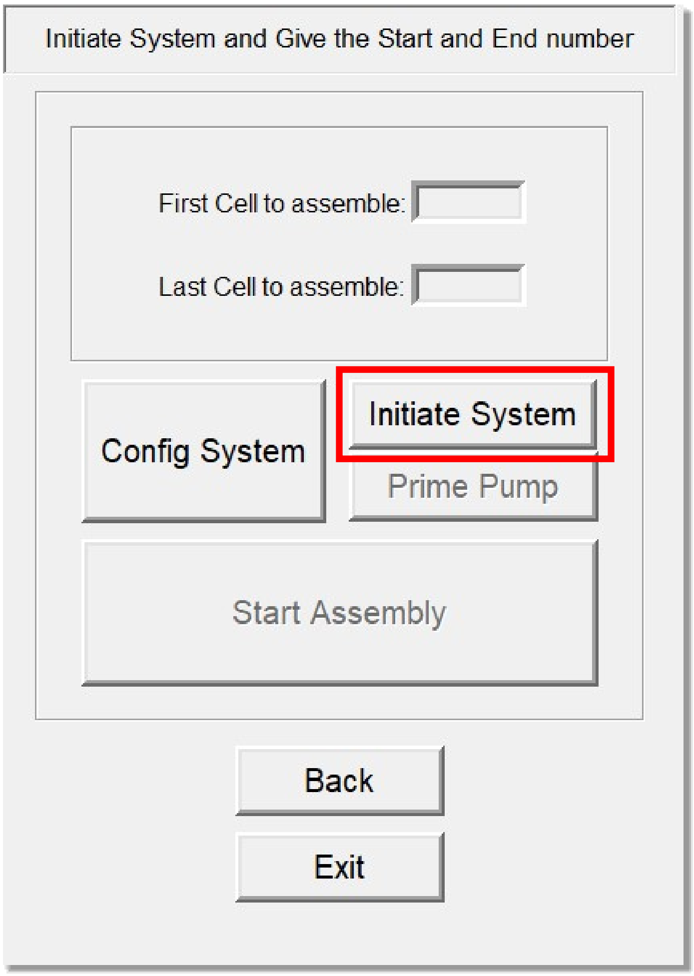
    1.2. Install all the module dependencies according to our "requiments.txt" file, you can also import all the necessary modules directly by using Anaconda.

2. Launching AutoBASS

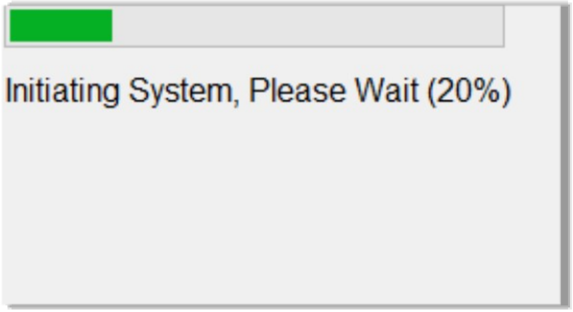
    2.1. Run “AutoBASS.py” to launch the GUI, you will see the start menu, to start the assembly procedure, click the “Assembly Coin Cell” button



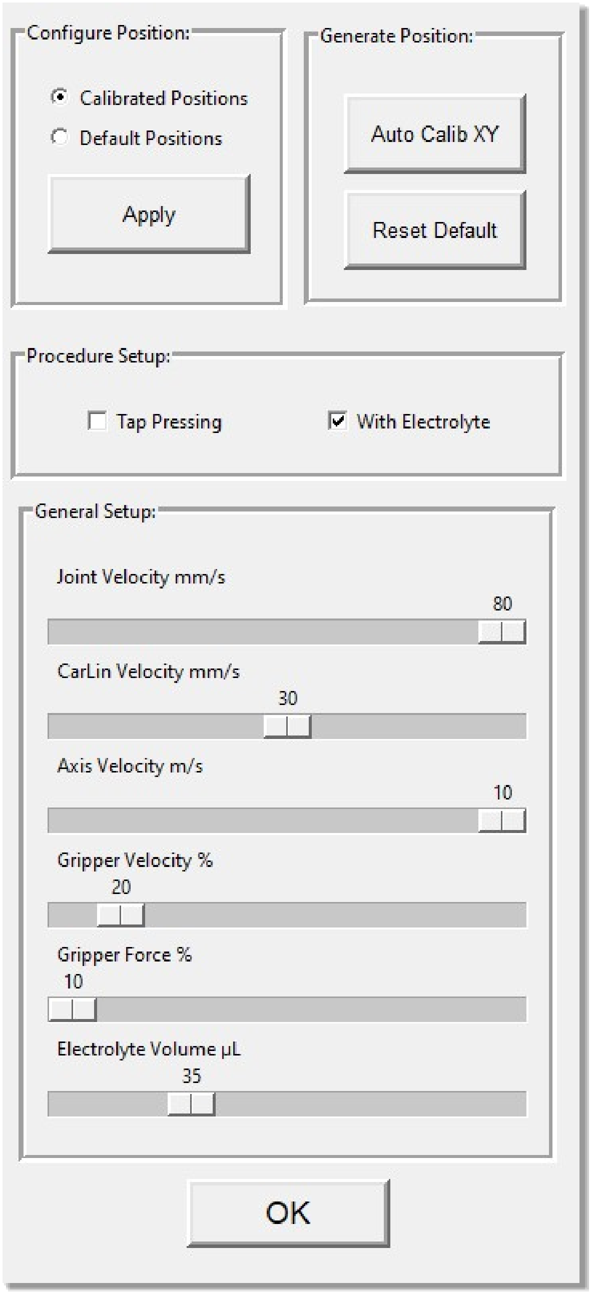

2.2. You will be now led to the “Cell Assembly Interface” menu, noted that some buttons and input fields are now disabled because the system needs to be fired up first.



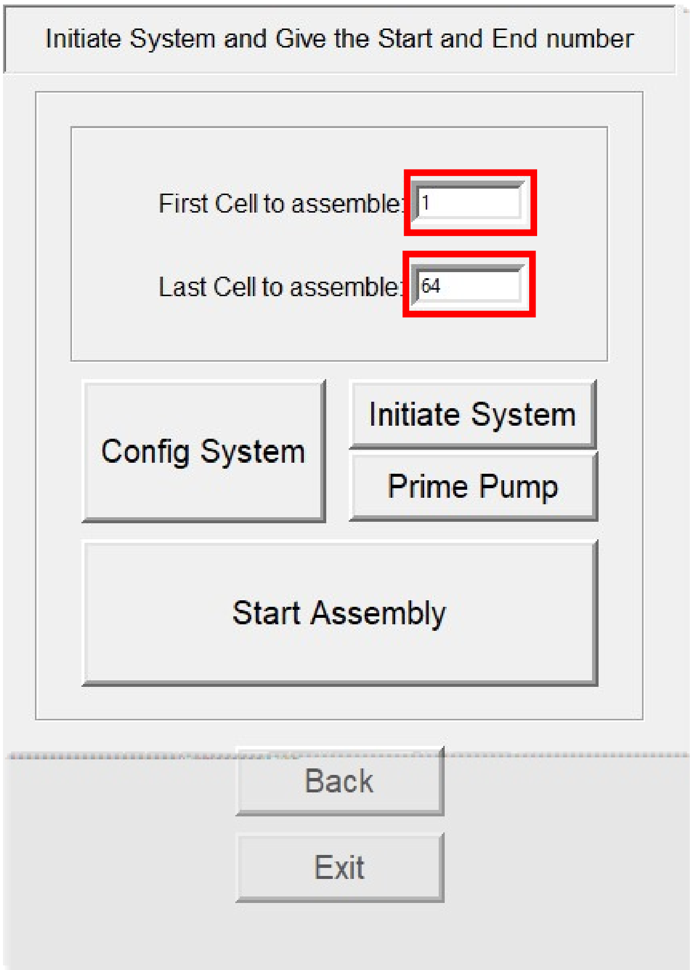
2.3. Click the “Initiate System” button and wait until connections to each instrument have been established and instruments been fired up:



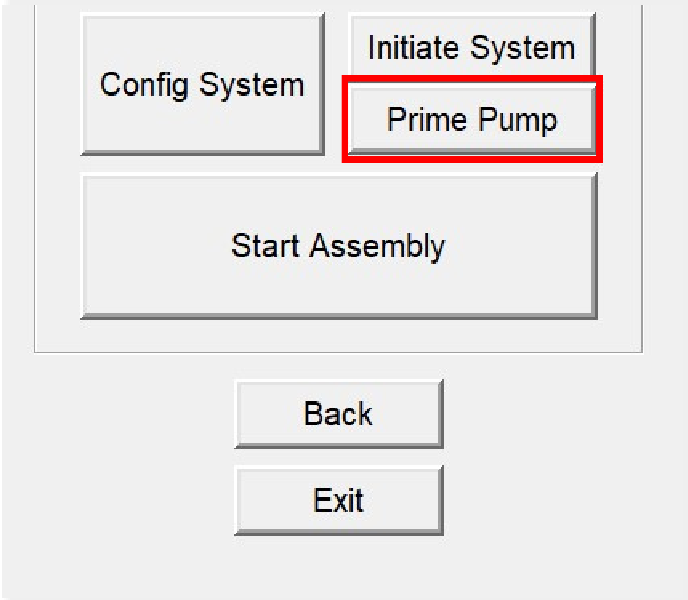

2.4. Now the system should be fired up and ready, click “Config System” to customize necessary parameters (such as volume of electrolyte) before assembly starts, and click “OK” to confirm those settings:



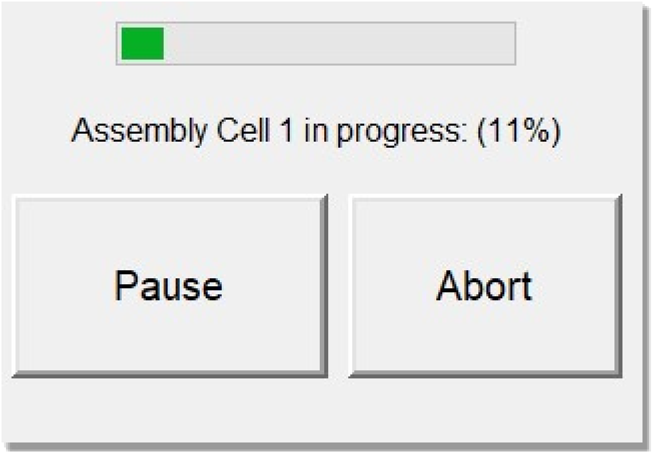

2.5. Put in the tray numbers you want the robot to perform assembly, the robots will then perform assembly following the sequence from the first number to the last number you put, but please make sure these trays are already loaded with all the components needed.




2.6. Next, click “Prime Pump” to fully fill the pipeline connected to the pump, now the system is all set, click “Start Assembly” to run the assembly procedure:




2.7. The assembly is now running, and a progress bar will pop up to show what the status is, you can click the “Pause” or “Abort” button any time to interrupt the process but note that with the “Abort” function, the procedure will be irreversible.




2.8. After done with the assembly, you will be led back to the “Cell Assembly Interface” and ready for the next assembly.