

To create devices where we can measure the electronic properties referenced in [1], metallic contacts need to be added to the graphene to measure electronic flow through the device.

To do this, lithography can be used to create polymer structures that allow the deposition of desired material in 2D geometries. This process and the adjustments made for fabricating our devices are described in the sections below.

### 0.0.1 Lithography

Lithography typically consists of three steps.

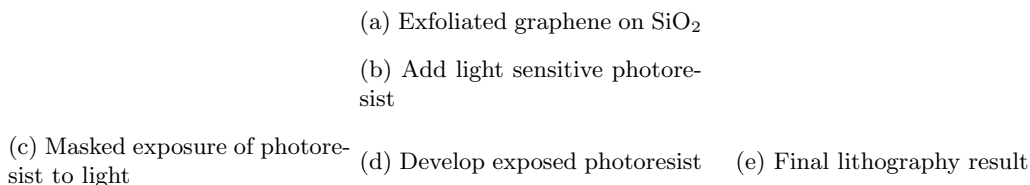


Figure 1: Common steps of lithography

1. Spin coating - covering your sample with a uniform layer of polymer.
2. Exposure - exposing the polymer to light changes the chemical compounds and properties. This differentiates exposed areas to those unexposed.
3. Developer solution - developer solution removes indented areas of photoresist to create structures.

#### Spin coating photoresists

A spin coater is used to deposit thin films of materials. A vacuum is used to hold a sample horizontally on the spinner, before drops of photoresist are dropped onto the sample. The sample is then spun over sometime to achieve a uniform thickness of the photoresist, before baking on a hotplate occurs to set the sample.

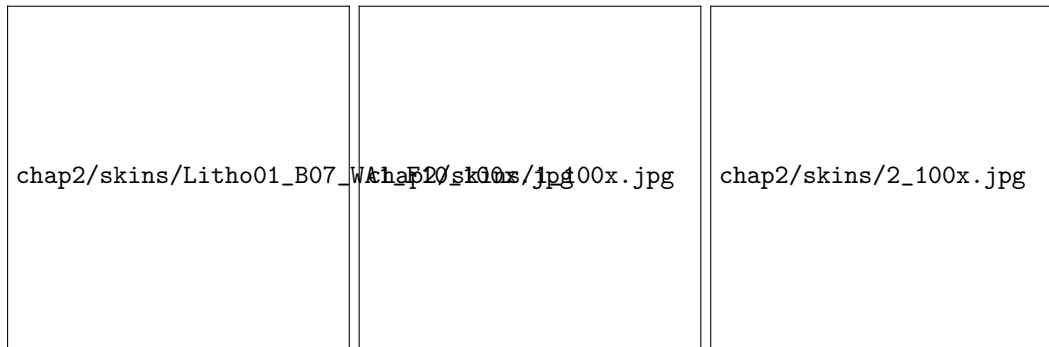
Photoresists vary in their spinning thickness, but also their exposure rates. Positive photoresists dissolve in developer when exposed to light, while negative photoresists dissolve if not exposed to light. We have only used positive photoresists, as we have primarily been creating structures for deposition, and not etching material (protect your sample, but remove everything else).

**HMDS & AZ-1512HS** Initially devices were fabricated using the AZ-1512HS polymer, with the additional use of hexamethyldisilazane (HMDS) as an adhesion promoter between  $\text{SiO}_2$  and AZ-1512HS. Devices were spun initially for 10 s at 1000 rpm, before being spun between 2000 and 3000 rpm for 30 s, per resist layer. This leaves a thickness of  $1.7 \mu\text{m}$  to  $1.39 \mu\text{m}$ <sup>[7]</sup>. Devices were then baked at  $100^\circ\text{C}$  for 1 minute.



Figure 2: Spin curve of AZ-1512HS (Source: EMD Performance Materials<sup>[? 1]</sup>)

**Skin issues with HMDS** When using HMDS and AZ-1512HS in conjunction, significant amounts of deposition remenants were found on samples as seen in .



(a) After metal lift off      (b) after 5s ultrasonication      (c) after 10s ultrasonication

Figure 3: Material remanants from lithography

This is likely a result of initial layers of metal deposition (ie, Chromium, see ??) forming layers on the sides of the developed lithography wells, as the skins have very similar geometry to that of either the wells or the edges. Further evidence that supports this is that the spinning speeds give resist heights (ie, the well edge heights) roughly the same as feature width ( $\approx 1\mu\text{m}$  minimum).

Sometimes these remnants could be cleaned off, through the use of ultrasonication, however this had a large risk of damaging the graphene, seen in ??.

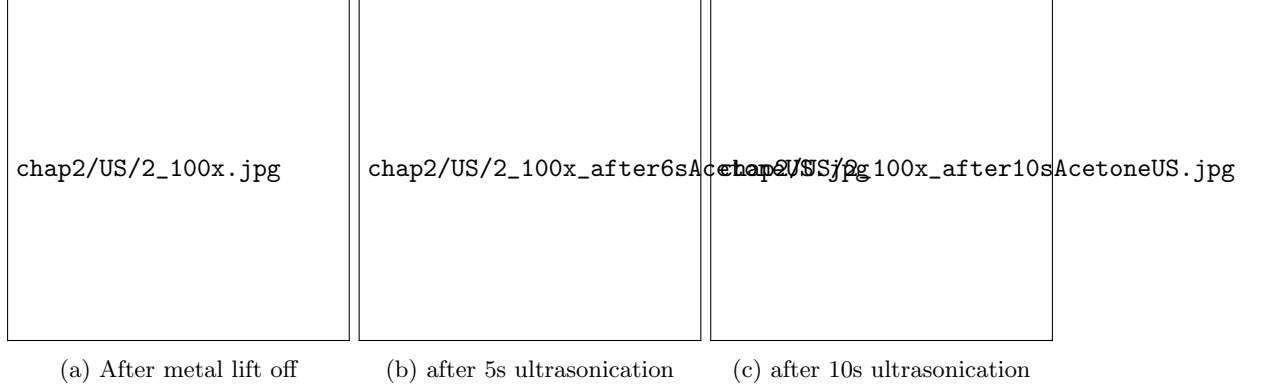


Figure 4: Material remnants from lithography

**LOR-1A & AZ-1512HS** An issue with a single layer photoresist processes is that well edges allow deposited materials to adhere, leaving 'skins'. One way to prevent this from happening is to use a multilayer process. Two resist layers are spun onto the sample, with the bottom film being more sensitive to the lithography process than the top (ie, develops faster, or is more sensitive to exposure). When developed, the bottom layer *undercuts* the top layer, stopping adhesion to the edges of the well when material is deposited. This process is depicted in ??.

Figure 5: Bilayer lithography process

Rather than a photoresist, LOR-1A is a lift off resist. When the films are exposed to the developer, LOR-1A is also lifted off with the soluble AZ-1512HS. Additional material is pulled and dissolved from the well, leaving the desired undercut effect.

## Exposure

After spinning, a mask writer tool is used to expose the wafer and resist films to UV light to develop desired pads. A mask writer usually is composed of a DMA (Digital Mirror Array) which allows filtering to pixel like squares.

An important parameter played with in this process is the exposure time, which affects your ability to develop fine structures. By using an array of different exposure times (??), we were able to optimise our feature exposure for a typical developing time.

Figure 6: Developing an exposure array on  $\text{SiO}_2$

Prepared CAD files, that specify the structure for desired contact pads onto devices, are used by the DMA to iteratively expose small areas of the film. These exposed areas undergo a chemical change, changing the structural properties for development.

### **Developers**

Developers are used to dissolve exposed / unexposed areas of photoresist films. For example, we use AZ-726 in conjunction with AZ-1512HS. Using a development time complementary to your exposure time is important to not overdevelop your features, as material in proximity to exposed areas is at risk of some structural damage. Developers do still affect the remaining structure over time.

### **0.0.2 UV Ozone surface preparation**

Large resistances can occur when trying to make contact with graphene. This can be for a variety of reasons. Resist residues between the deposited pads and graphene can be insulating, non-metallic bonding between deposited metals and graphene, or oxidation of metals being deposited (ie, chromium oxide).

We use UV Ozone to clean the graphene exposed in our developed wells. UV Ozone cleaning blasts the surface with UV ozone light, while flowing oxygen gas. Overtime surfaces are slowly etched and material that is not strongly bonded is cleared.

In our optimisation we ran two wafers with devices at times of 5m and 15m respectively (see ??). The 15m devices were etched away completely, however the 5m device provided the first low resistance contact observed, after many iterations of devices.

Figure 7: Cleaning before and after UV Ozone

### **0.0.3 Deposition**

Once a designed structure is exposed to make contacts with graphene,

### **Oxide Protection**

### **0.0.4 Lift-off**

### **Ultrasonication**

### **0.0.5 Oxide transfer**