Project Papyrus: Paper Feel on Displays

Tim Large, Jim Holbery, Robert McPherson

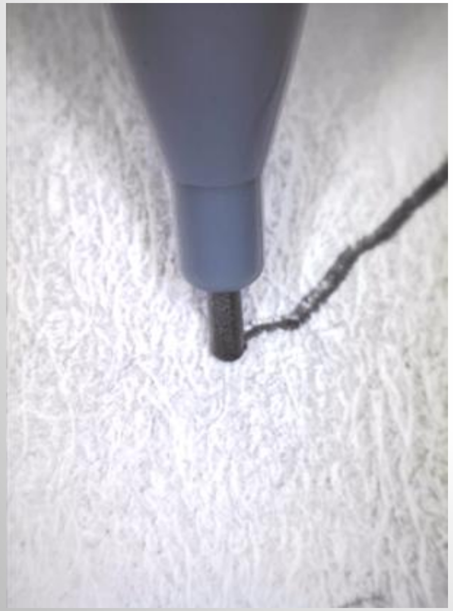
Project Aim

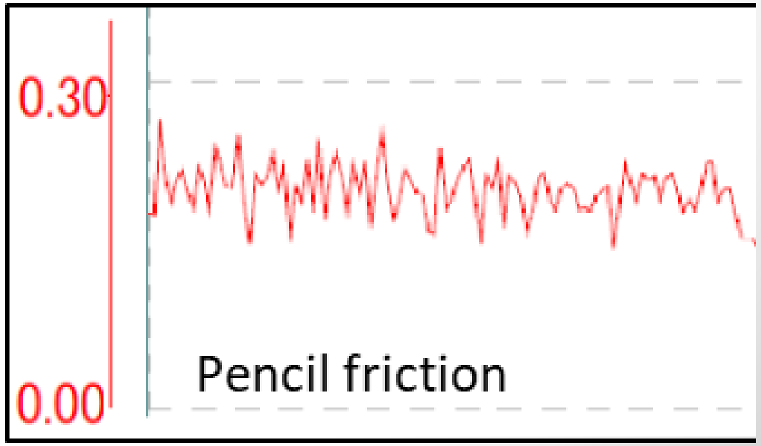
- People who write or draw tend to like the feel of paper, and it would be ideal to add the feel of a paper-like texture to displays for pen interactions.
- The traditional way of achieving this is to add a texture to the glass display surface.
- Texture is typically added as a secondary film or etched into the front surface.
- Unfortunately surface textures compromise the resolution and contrast of the display.
- Apparently paradoxical requirements like this are a fertile ground for innovative ideas.

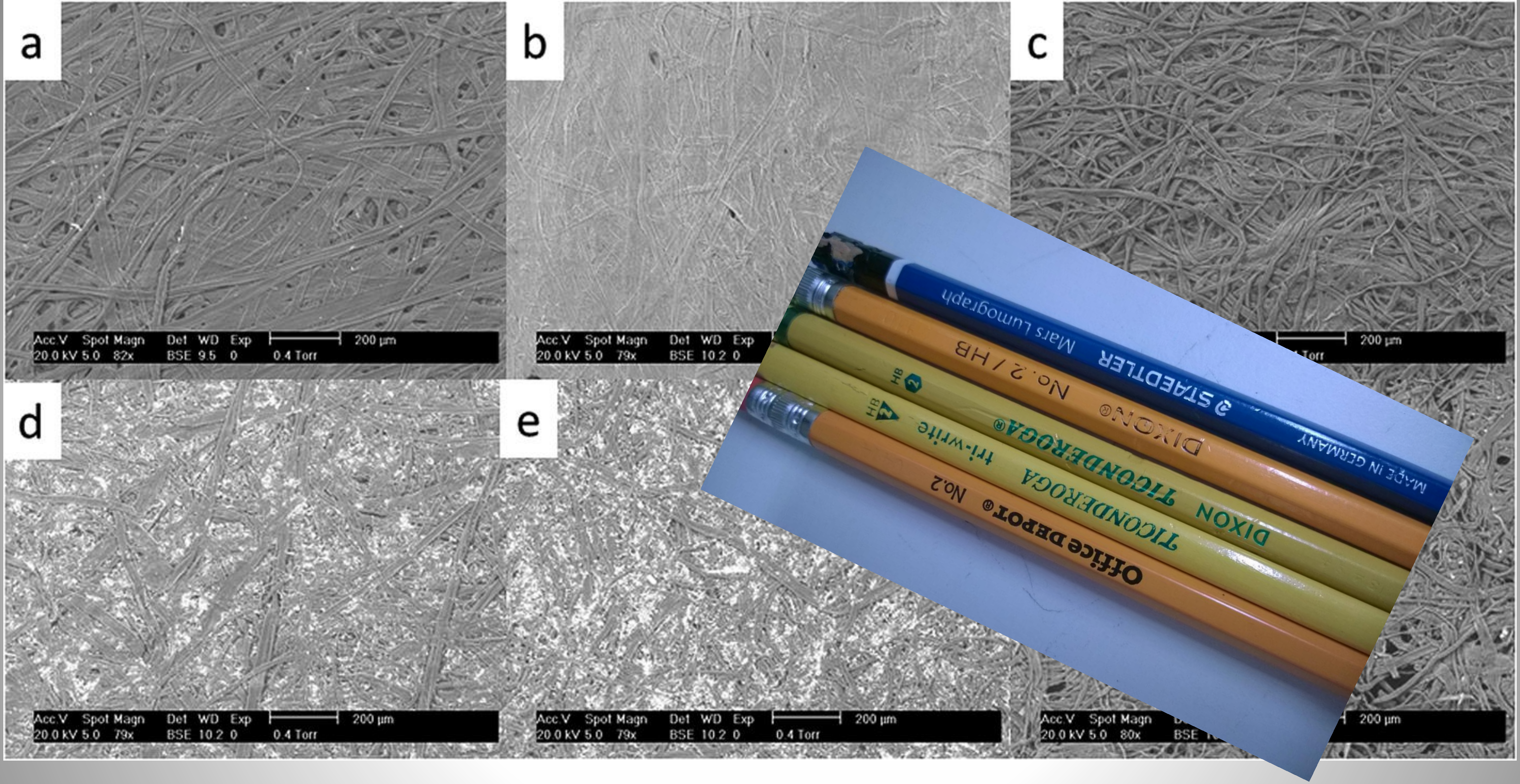
Surface structure of office paper (0.5x0.5mm)

What happens when a pen moves across paper?

- The pen explores the surface changing surface height, plasticity and elasticity of the paper fibers.
- Movement creates varying vertical and lateral forces that the user feels as vibrations.
- In this project, we aim to re-create the lateral forces, but without varying the surface height. The lateral forces can be measured as *coefficient of friction (COF)*.





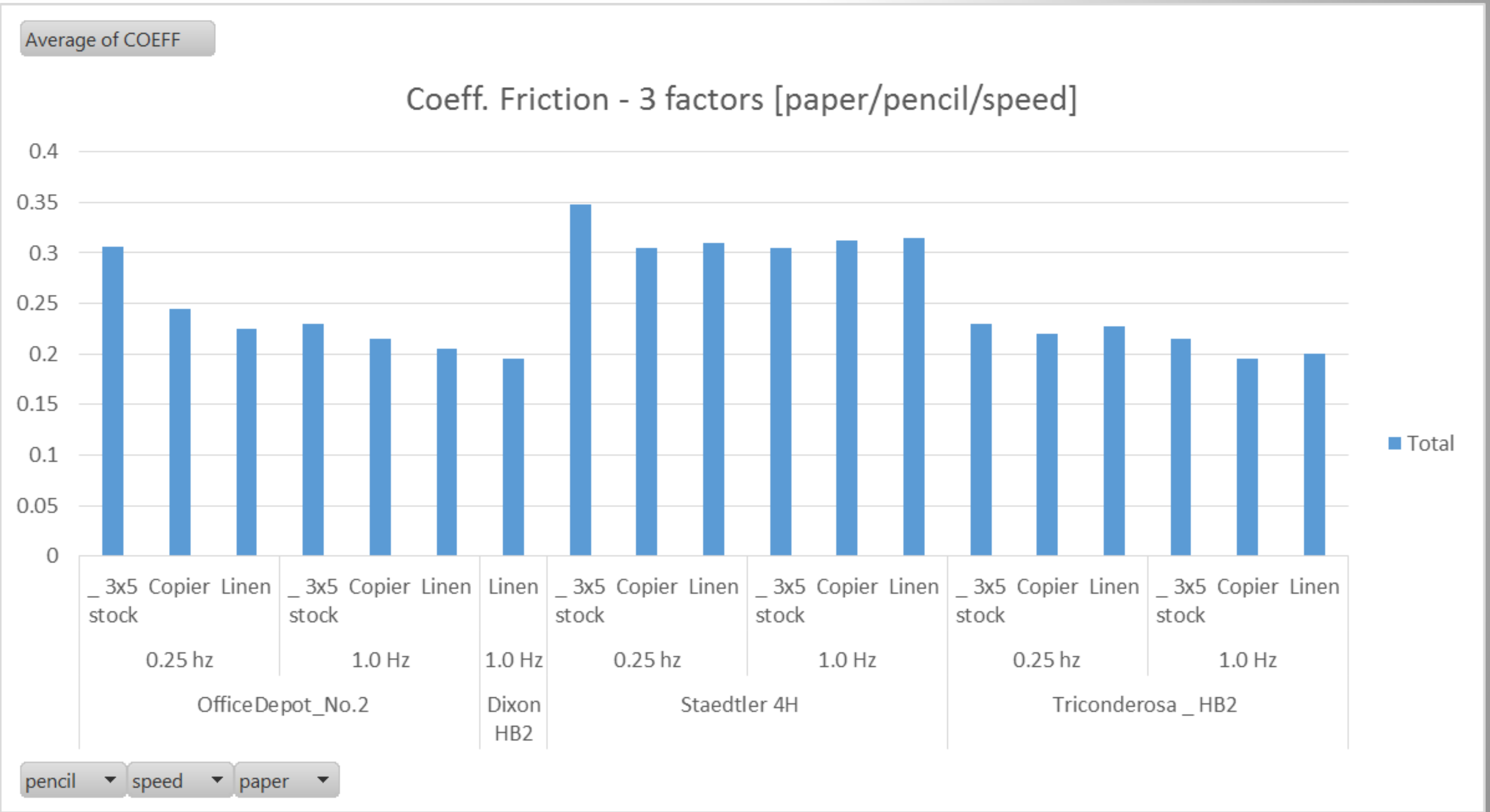


SEM images showing different paper types: (a) brown compostable bag, (b) cigarette paper, (c) filter paper, (d) newspaper, (e) photocopier paper, (f) tissue paper.

Picture from http://pubs.rsc.org/EN/content/articlehtml/2015/ta/c5ta00687b

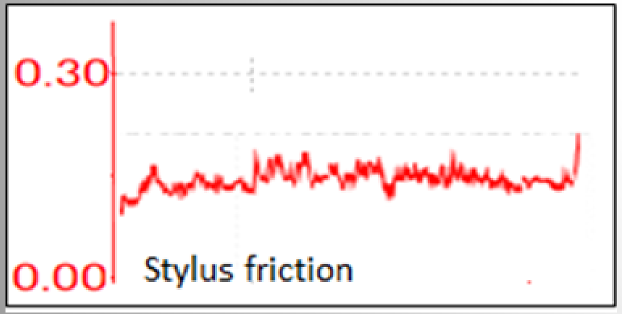
Product range paper & pencil

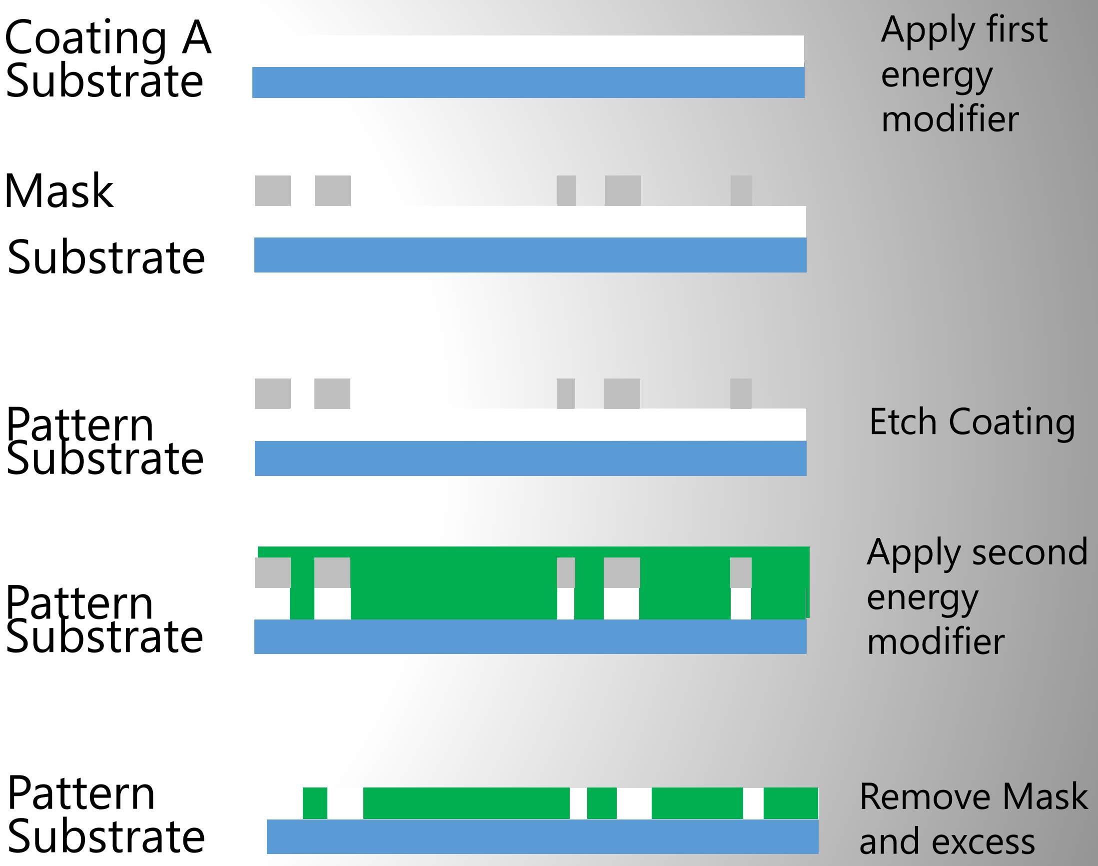
- Coefficient of friction is measured using a tribometer for a range of pencil and paper types.
- The COF ranges from 0.2-0.35.



Creating varying friction

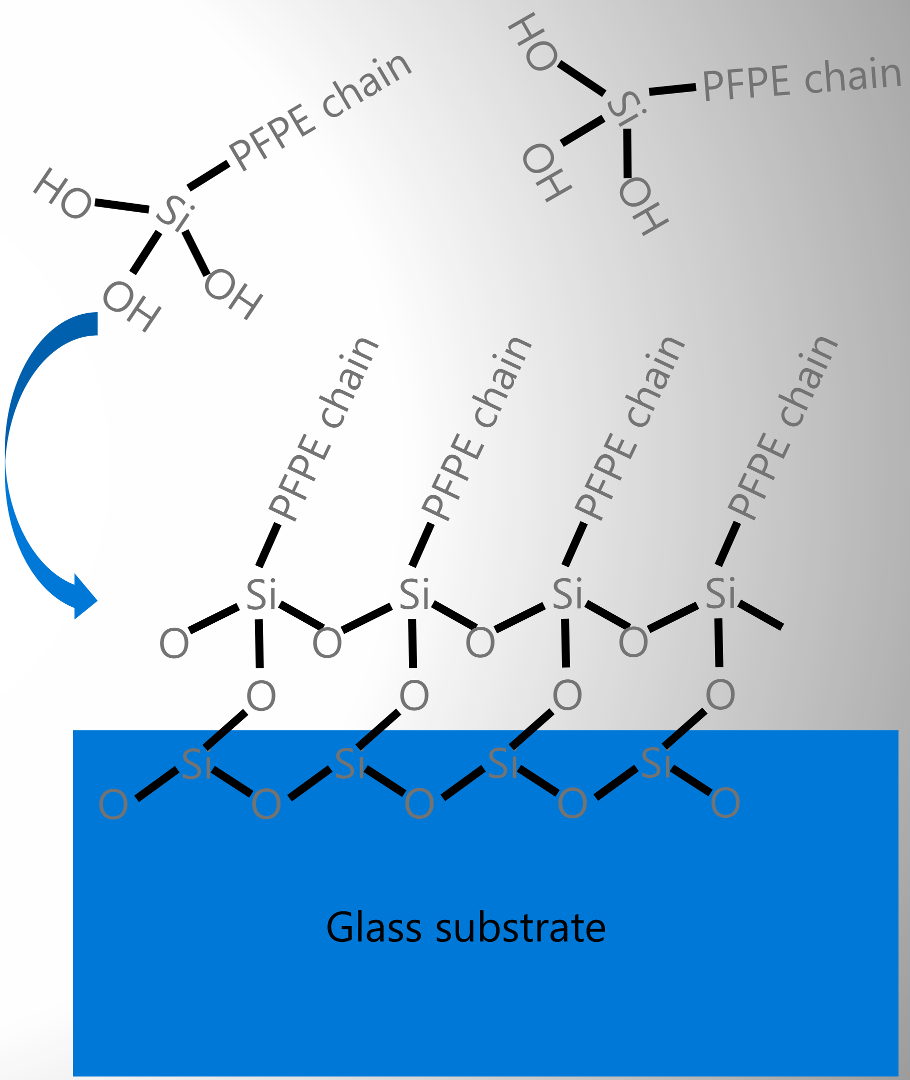
- By patterning using two different surface energy treatments , we can create a variation in coefficient of friction.





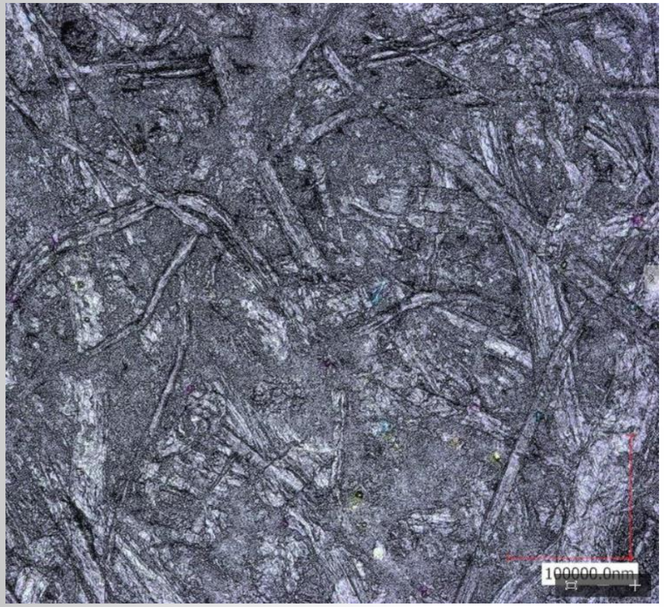
What materials produce no optical effect?

- We want to pattern only the coefficient of friction, not the surface topology
- We do this using perfluoropolyether surface energy modifiers, chemicals containing carbon, silicon and fluorine.
- These chemically bond to the glass via Si-O bonds, resulting in a surface layer around 10nm (100 atoms) thick.

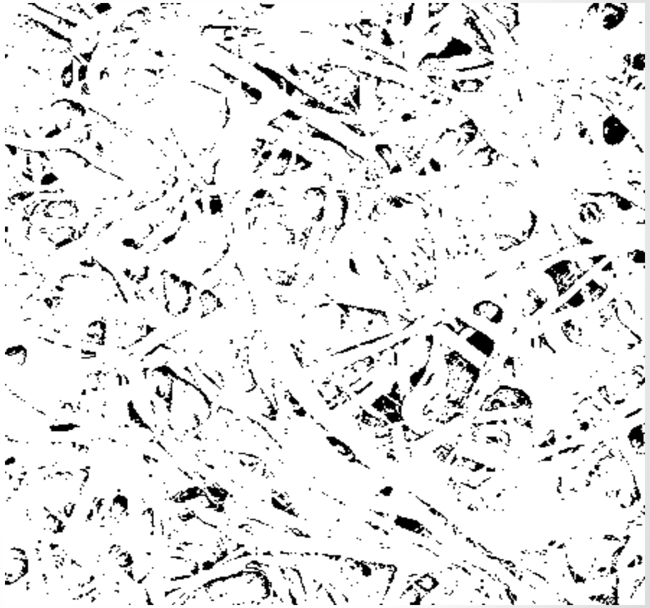


What kind of surface do we want?

- We created a mask based on the surface characteristics of copier paper



Common copier paper



Binarized image

Spatial frequency distribution

- The fiber distribution in paper is not regular and the randomness follows a power law spatial frequency distribution.
- We want to replicate this in the mask to get the “feel” similar to paper.

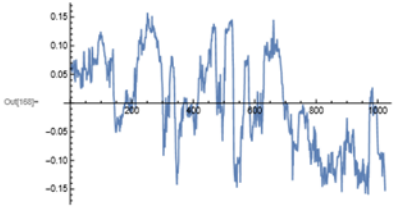
Remove the redundant data and scale down raw counts

```
data = Drop[raw[[1]], nlinestoremove]ᵀ;
delta = data[[2, 2]] - data[[2, 1]];
(*Point spacing - for calibration of frequecies*)
stripped = Flatten[Drop[data, ncolumnstoremove]];
flattened = (stripped - Mean[stripped]) / Max[stripped];
```

Plot the stripped and flattened data

```
In[168]:= ListLinePlot[flattened]
```

Out[168]=

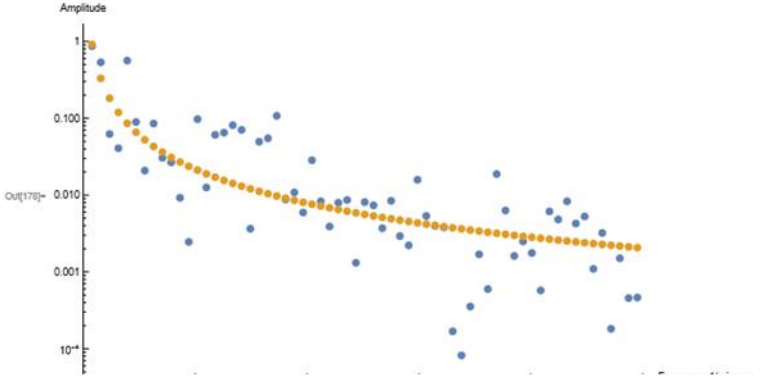


Get the Fourier Transform, absolute value and spectrum

```
In[100]:= ft = Fourier[flattened];
absft = Abs[ft];
powerspec = absft^2;
nodc = Drop[powerspec, 1]; (*Drop the DC term*)
nodc = Take[(nodc + Reverse[nodc]) / 2, {1, Floor[Length[nodc] / 2]}];
(*Mirror the data back on itself to use both halves of the data*)
```

```
In[178]:= ListLogPlot[{{Range[Length[clipped]] / Length[ft] / delta, clipped}ᵀ,
  Table[{f / Length[ft] / delta, Exp[linmodel[Log[f]]]}, {f, 1, Length[clipped]}]},
 AxesLabel → {"Frequency 1/microns", "Amplitude"}]
```

Out[178]=



Assume a power law fit

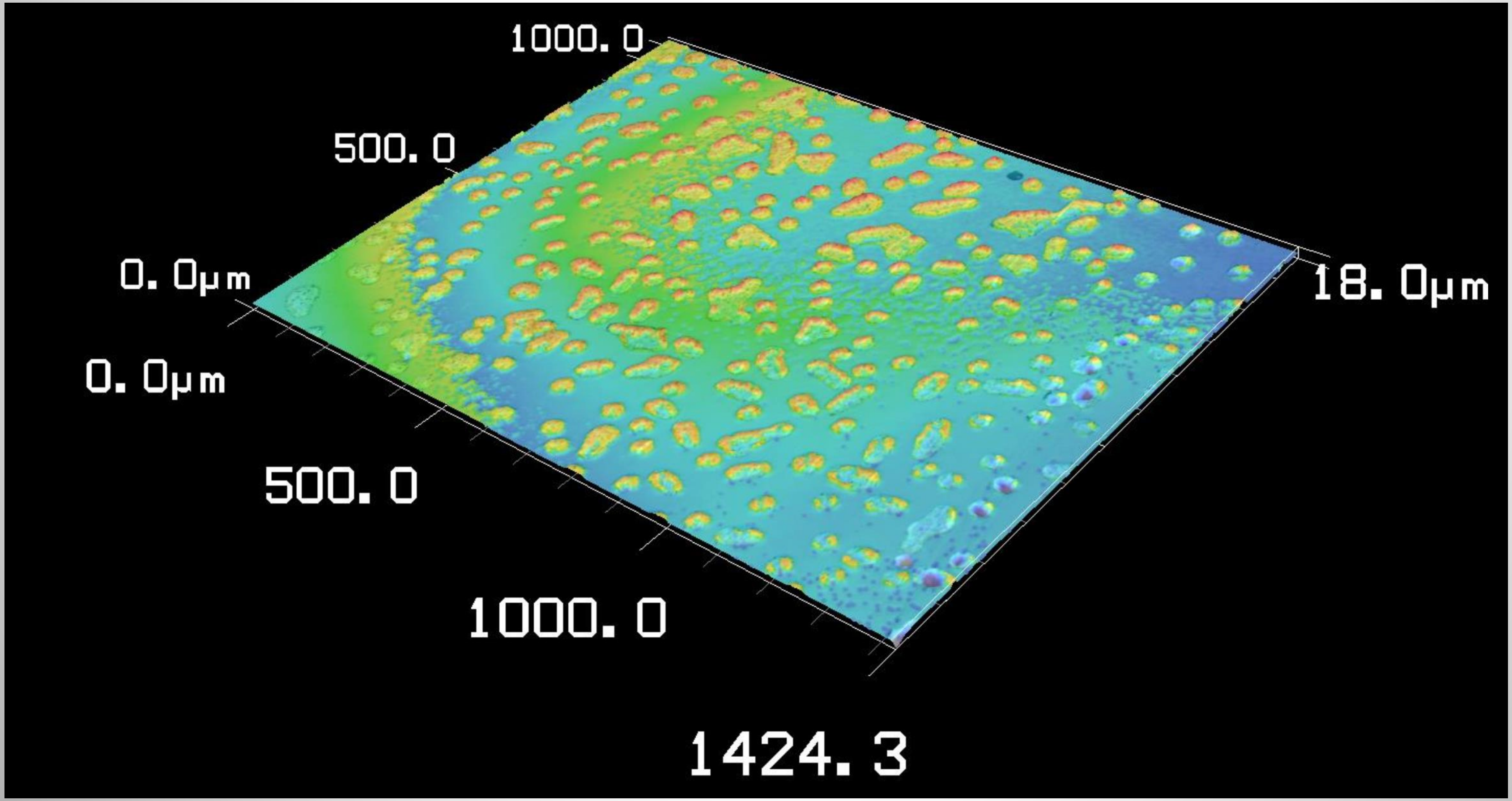
First, transform to log.

```
In[146]:= log = Log[clipped];
linmodel = LinearModelFit[
  {Log[Range[Length[log]]], log}ᵀ, f, f, Weights → 1 / Range[Length[log]]]

Out[147]= FittedModel[ -0.0871383 - 1.47043 f ]
```

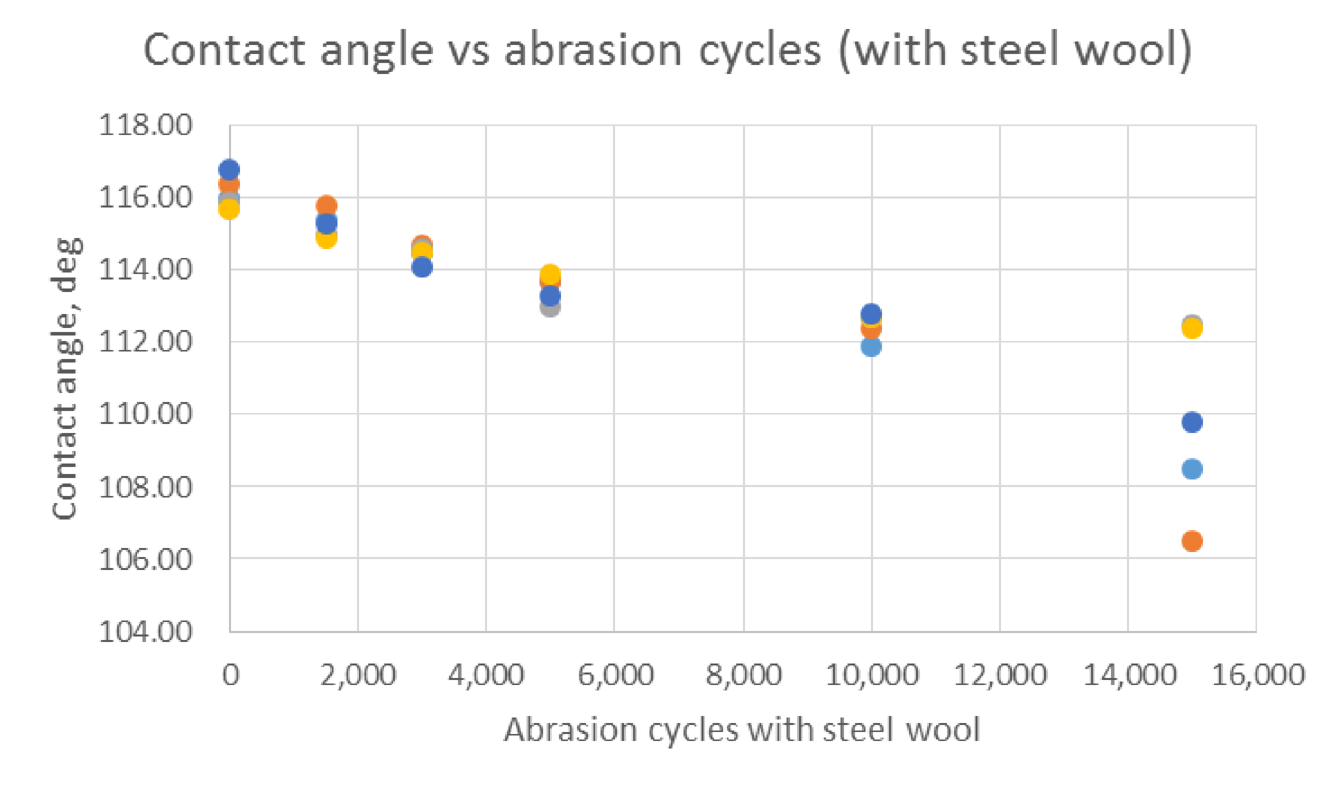
Mask

- This shows a height map of the mask applied to the glass surface



Reliability – Wear Abrasion

- Samples show almost no wear up to >10,000 steel wool abrasion cycles.



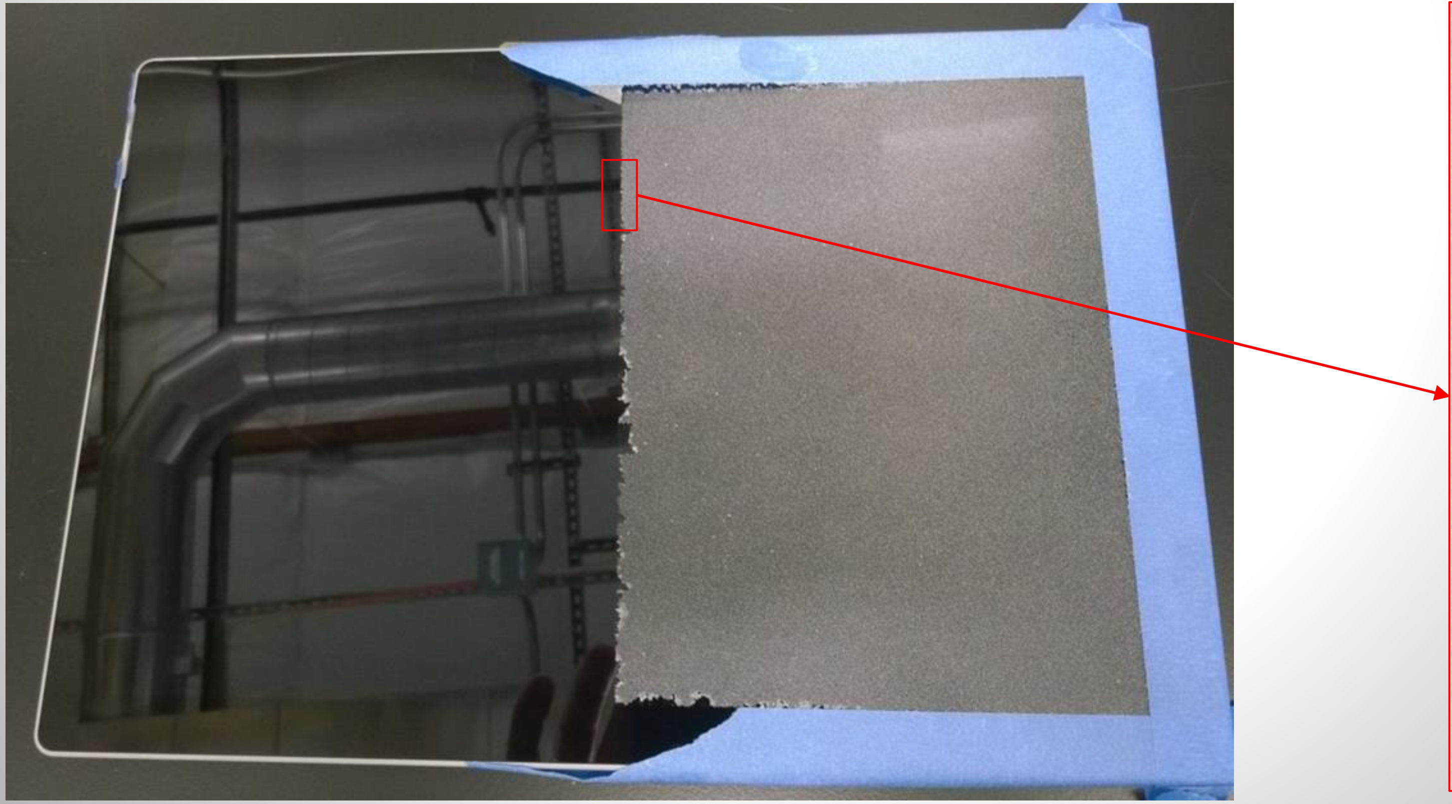
25mm square steel wool pad with 0.5kg applied.

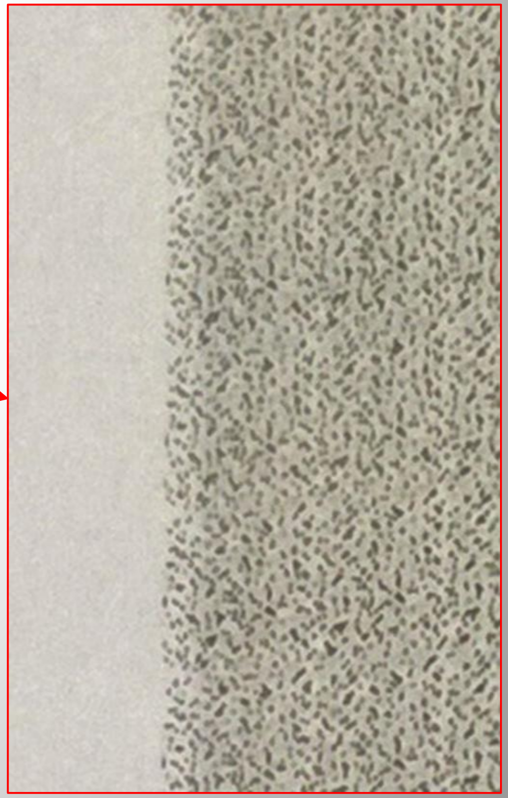
Wear is determined by change in surface contact angle.

Large changes in contact angle indicate the surface treatment is wearing away.

Application to a device

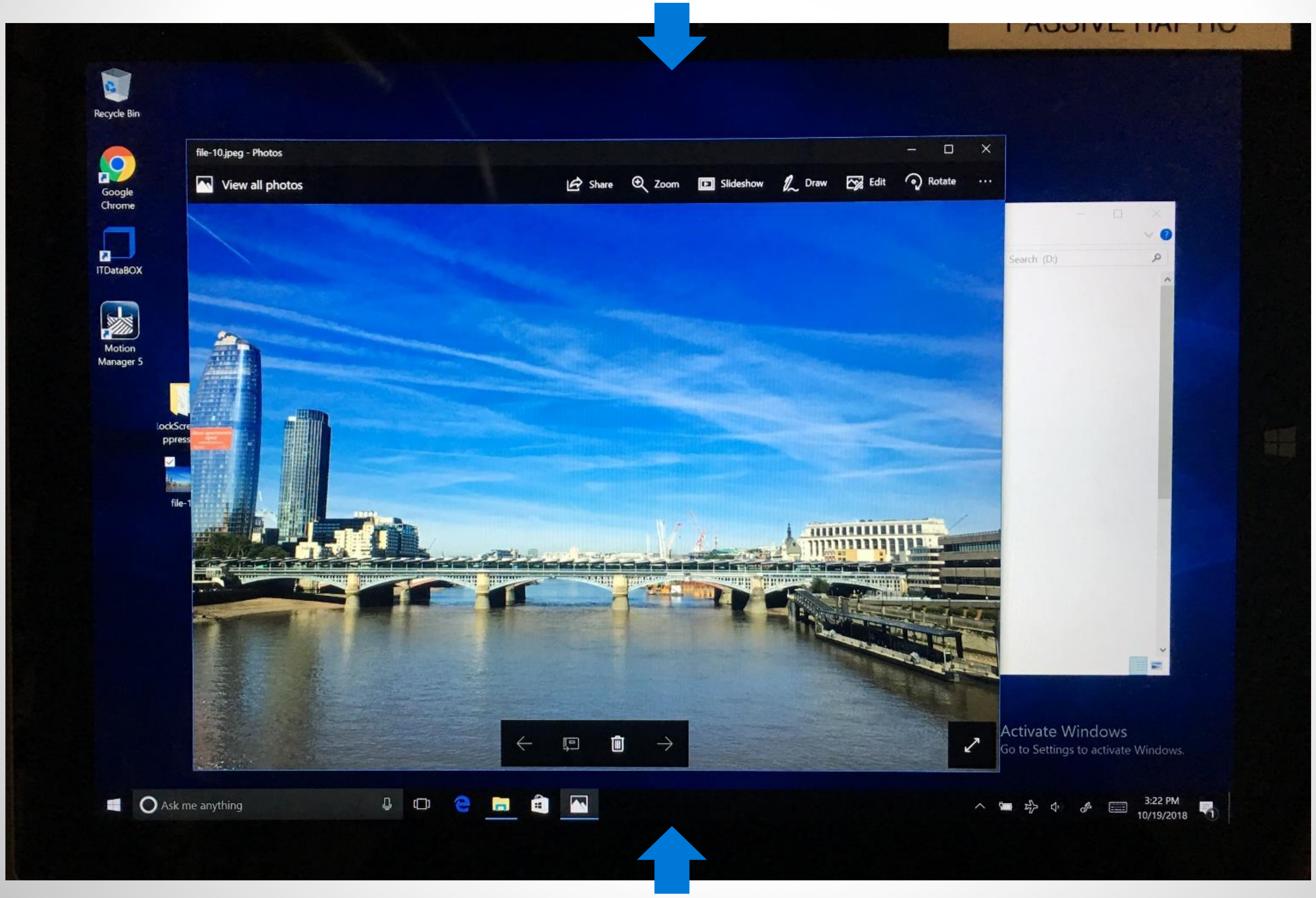
- The mask is applied to a Surface Pro device.
- The existing surface treatment is removed using oxygen plasma treatment.
- The second layer is applied, then excess and mask material removed.





Finished Device

- Since the surface treatment is only nanometers thick, it is entirely invisible.



Blue arrows indicate line between masked and original layers.