# Scalable, Printable, Surfactant-free Graphene Ink Directly from Graphite

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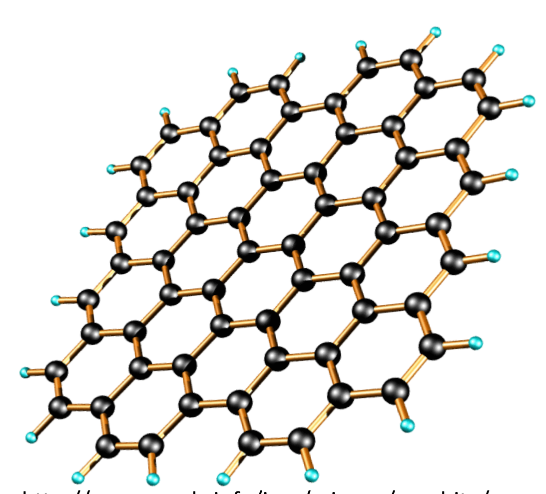
## Abstract

We developed printable graphene ink in ethanol and water free of any surfactant. We used a solvent-exchange method to match the surface tension of the cross-solvent with the graphene surface energy. Using this clean graphene ink, a transparent conductive film can be obtained on a PET and glass substrate through rod-printing. After inspection, dc/optical conductivity was measured to be among the highest of directly deposited graphene ink. The as-fabricated graphene ink is stable for at least half a year. This is the first demonstration of scalable, printable, surfactant-free graphene ink derived directly from graphite.

## Background

- Graphene is a one atom thick layer of carbon atoms arranged in a honeycomb shaped lattice.
- Graphene's hexagonal structure allows it to be the strongest material in the world for its size and thickness.
- It also has excellent electron mobility and little electrical resistance.



http://www.ewels.info/img/science/graphite/

- Graphene's durability and electrical properties make it an ideal material for printable electronics.
- The graphene in our research is created through ultrasonification—based on the solution exfoliation approach.
- When graphene is placed in a solution of water and ethanol, the new mixture can be dried onto a substrate and used as a highly conductive film.
- Generally, inks like this need a surfactant to help the solution adhere to their substrates.

## Surfactants vs. Solvent Exchange

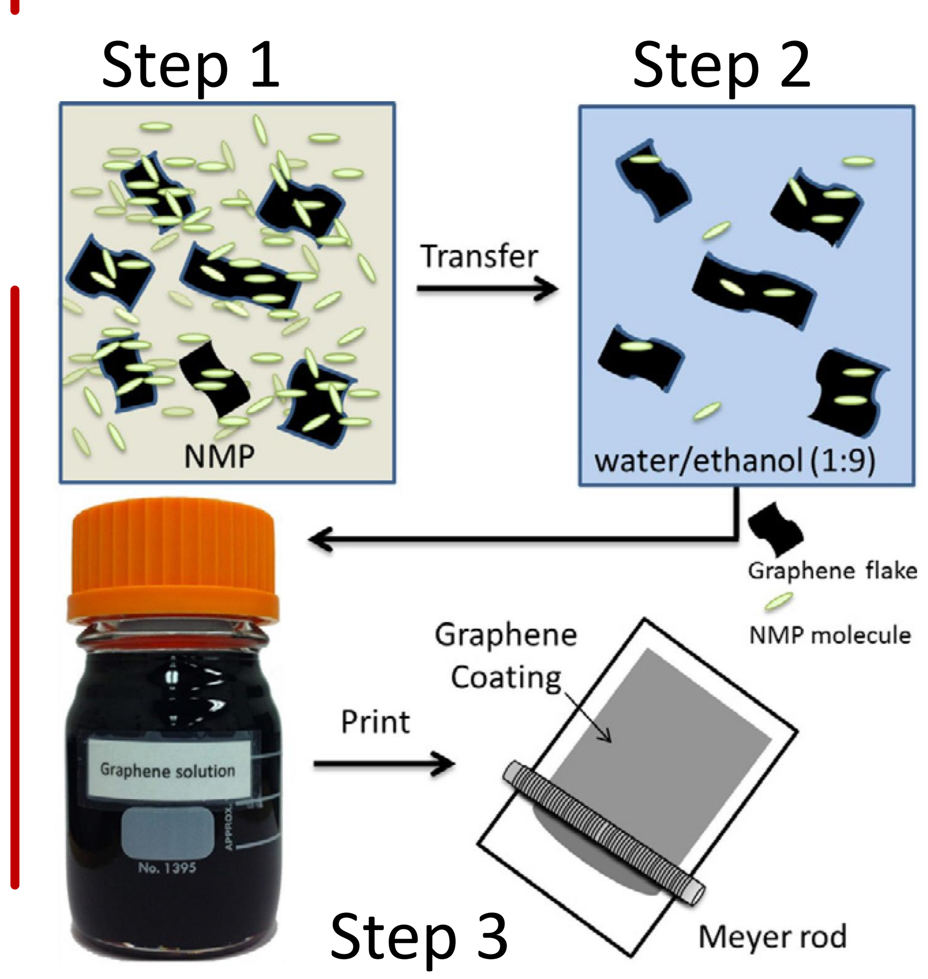
- Surfactants are chemicals used to decrease the surface tension between two materials
- However, when a surfactant is mixed with an electrically conductive material, the resulting mixture produces the effects of an insulator.
- Instead of using surfactants, we utilized the solvent exchange method to maintain conductivity and reduce toxicity while offering a new viable option in producing graphene ink.
- Solvent exchange incorporates a mixture of water and ethanol.
- We first needed to optimize the ratio of our solvents, water and ethanol, to maximize their surfactant qualities. After attempting several mixtures, we concluded that the optimal ratio between water to ethanol is 1:9.

## Step 1 Preparation of NMP Solution

1) 200 ml of NMP is mixed with 0.66 g of graphite flakes in a flask.
2) The flask is placed in a sonicator to peal off layers of graphene from the existing graphite.
3) The upper 150 ml of the solution is removed and kept for a future transfer.

## Step 2 Transfer to Ethanol/water

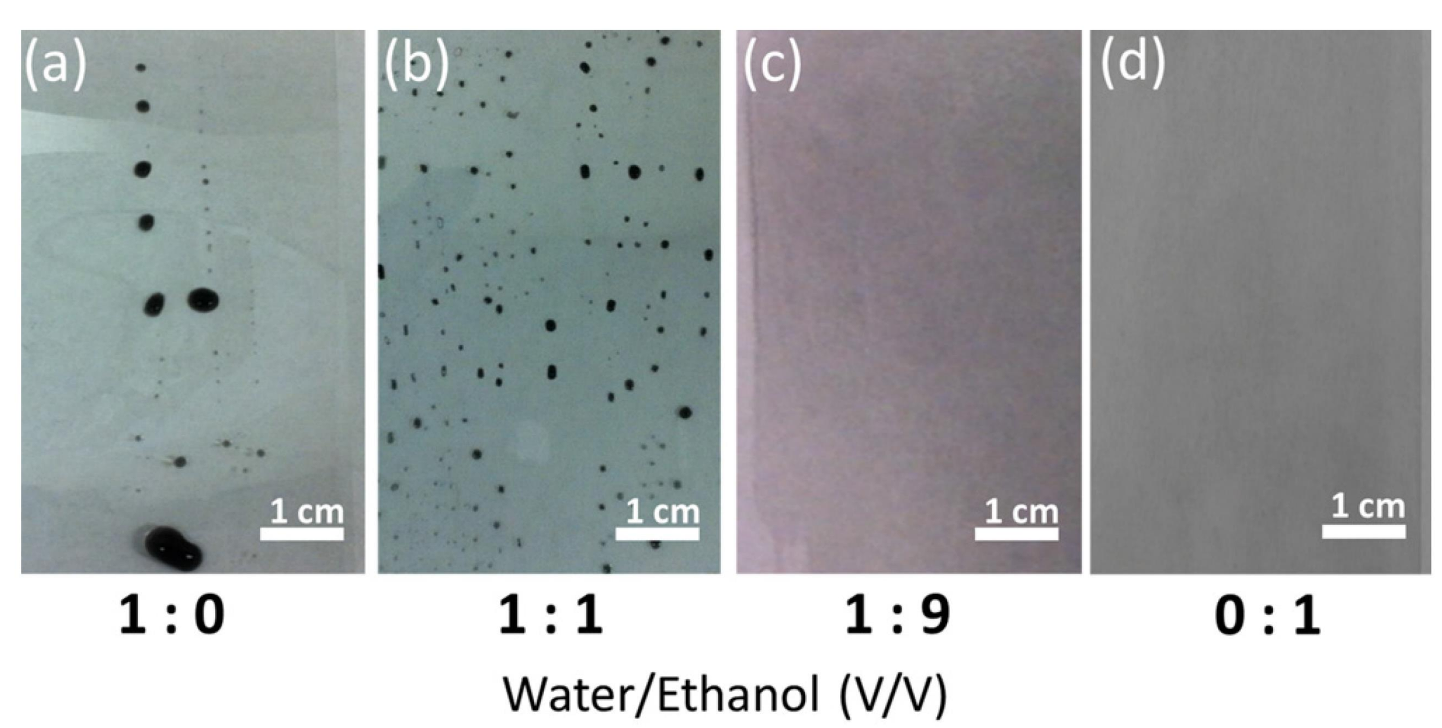
1) 20 ml of resulting solution is vacuum-filtered.
2) The resulting solid is mixed with 20 ml of water/ethanol with a 1:9 volume ratio.
3) The new solution is put in a centrifuge and sonicated once more for several minutes.




## Step 3 Printing

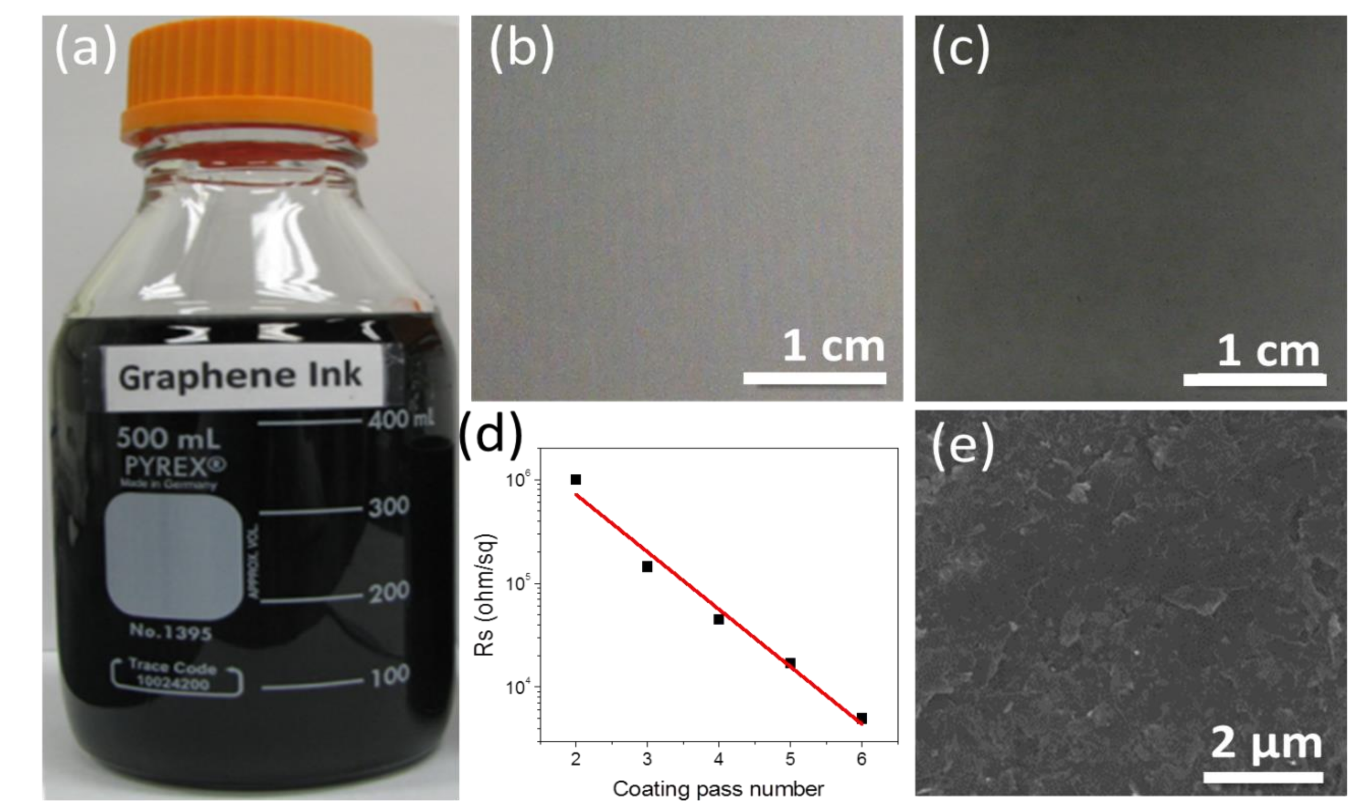
1) 100 µl of the solution is spread onto a glass substrate for printing.
2) A wire wound shaft called a Meyer rod is pushed across the glass substrate and graphene solution in order to evenly spread a coat on the surface.

## Print Graphene on PET

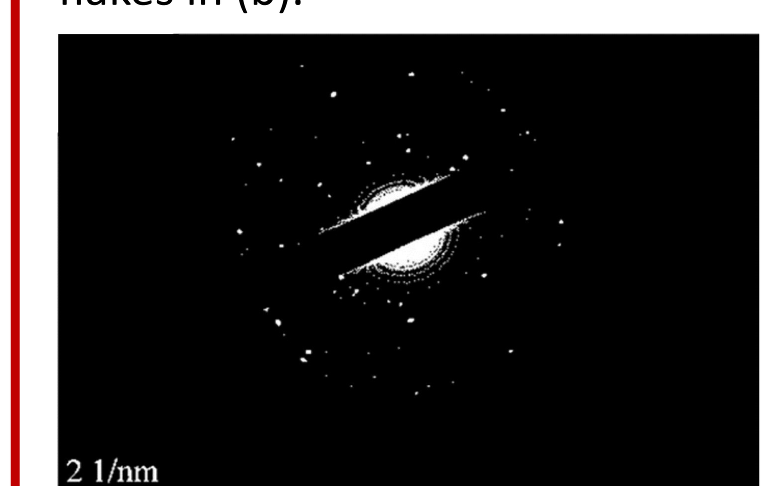



During this experiment, we searched for the best ratio between water and oil for our solvent exchange method. While increasing the quantity of ethanol from (a) to (b), the wetting/adhesion improved. Since the ethanol evaporated more quickly than the water, droplets formed while drying, leaving stains. In (c), the water evaporated at the same time as the ethanol, optimizing the drying process. A pure ethanol mixture (d) was also created, but the graphene flakes did not disperse uniformly.

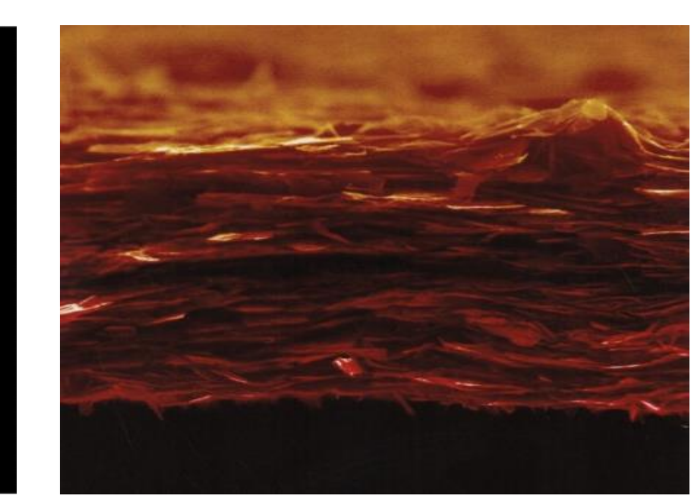
## Graphene Flakes in Ink




Above: (a) A picture of scalable and printable graphene ink with a volume of 500 ml transferred from NMP solution. The transfer yield is nearly 100%. Uniform graphene coating on plastic (b) and glass (c) substrates with a size of 3 cm x 3 cm, respectively. (d) Sheet resistance versus coating pass number on polyethylene terephthalate (PET) substrate. (e) SEM image of printed graphene flakes in (b).




Diffraction pattern confirms atomic structure of graphene.



TEM photograph of cross section of dried graphene ink.

- The image above and to the left indicates the lattice structure. The hexagonal pattern of dots that forms confirms that the material observed is graphene.
- The picture to the right depicts a scanning electron microscope photograph of a cross section of graphene ink after it had been filtered, printed, and dried.

## Conclusion

Our project successfully exhibited that conductive graphene ink could be cheaply synthesized and transferred to a substrate. By utilizing a solvent exchange method with an optimized water to ethanol ratio instead of a normal surfactant, we maintained the conductive properties of the graphene and reduced the ink's toxicity.