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High throughput transfer technique: Save your graphene

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ABSTRACT

The development rate of graphene-related research is tremendous. New methods of graphene growth and transfer are reported on a regular basis, trending towards large-scale. Nevertheless, the fabrication of high-yield and low-cost graphene devices is still challenging. In this work, we approach this problem from a technological point of view and propose a new, so-called "high-throughput transfer technique". The technique allows a semi-automatic transfer of graphene films right at the desired places on a wafer. We demonstrate the applicability of our method by aligning 52 graphene devices on a 4-inch wafer using only 4 cm^2 of graphene. The overall yield of this process is over 90%.

1. Introduction

Research on graphene has been a rapidly growing field in the last decade [1,2]. A vast amount of research has been conducted on its fabrication and growth [3]. Material qualities of graphene have been exploited very extensively: from low-dimensional and low-temperature physics [4] to studies of its biological [5–7] and environmental [8] properties. However, in order to fully exploit these properties, one must find an appropriate way of scaling up the graphene-based devices' production rate. This means that micromechanically exfoliated graphene, despite its advantages [4,9], is not an appropriate material. The chemical vapor deposition (CVD) growth of single-layered graphene is the most common, cheap and scalable technique, as described in detail elsewhere [10–13]. The CVD-grown graphene is probably the most applicable material in terms of quality, dimensions and growth parameters. State-of-the-art CVD-grown graphene displays grain sizes up to the millimeter-scale [14–16].

Nevertheless, transfer of the CVD graphene from a metal foil to a working substrate is still the most challenging and crucial step [17–19] of device production. The most commonly employed transfer procedure is wet-transfer, the so-called "fishing" transfer. However, it was shown that this method leaves many defects and residues [18–20], resulting in doping of and damage to graphene. A lot of research has been directed at modification of the method, e.g., extra annealing steps [21], modified RCA (Radio Corporation of America) clean steps [18], etc. Many different polymers are used as the support layer [19], some of which occasionally result in cleaner and less defective graphene. Nevertheless, still the most commonly used polymer for such a purpose is poly(methyl-methacrylate) (PMMA).

The fishing transfer is very easy for small pieces of graphene, up to one inch maximum. However, while scaling it up to 4-inch, 8-inch or even larger, several problems appear [22]. First, the large PMMA/graphene flake is very difficult to handle, and usually the transfer results in large number of cracks and folds. Second, even if the large piece is transferred successfully, later, during the fabrication of devices, most of the graphene will be etched away. Just a small amount of the initially transferred graphene is actually used, therefore the used/wasted graphene ratio (UWR) is extremely small. This is an enormous amount of wasted material. One possible solution to the problem would be transferring the dozens of small pieces directly to the sites of interest. But this is impossible by the standard fishing protocol. Transferring even just two graphene pieces on one target substrate precisely on the spots of interest, while keeping precise distance between the pieces, would be impossible via the standard method. Additionally, while drying out, the small pieces tend to move (up to several millimeters) from the initial region, drawn by tension forces of the water.

With the proposed method we can transfer graphene precisely onto the spots that will be used. This is done via patterning the substrate into regions where graphene must be and transferring

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graphene only there, instead of transferring graphene on the whole wafer. The pattern transferred can be chosen according to the substrate design. Then, by means of the proposed method, the graphene pieces of specified size are transferred right into spots of interest. Moreover, the proposed technique prevents the pieces to move away from their spots while drying. The proposed solution minimizes the material waste, as well as simplifies and accelerates the transfer process for large scale transfer. In our case, from one piece of 2 cm × 2 cm graphene we can fabricate a whole 4-inch wafer (with 52 chips), instead of the four chips possible transferring the same area of graphene with the fishing method (Fig. 1).

We believe the technique can serve as a bridge towards more abundant and rational use of graphene in new state-of-the-art devices.

2. Materials and methods

2.1. Graphene growth

The graphene used in this work was CVD-grown on 25 μm thick copper foil for 30 min at 1000 °C. Argon at 200 sccm, hydrogen at 50 sccm and methane at 0.5 sccm under 12 kPa pressure was the gas mixture used. Prior to the growth, the copper foils were thoroughly cleaned in hydrogen chloride followed by subsequent acetone and isopropanol rinses. The Raman spectrum (Fig. S1) shows a continuous monolayer of CVD graphene.

2.2. The transfer chamber

We have designed our transfer chamber for wafer sizes up to four inches. The chamber contains six alignment columns, a wafer chuck and vacuum connections for pumping liquid through the system. The schematic of the chamber is illustrated in Fig. 2. The chamber body itself has one main role: to hold the target wafer and align it with the mediator film.

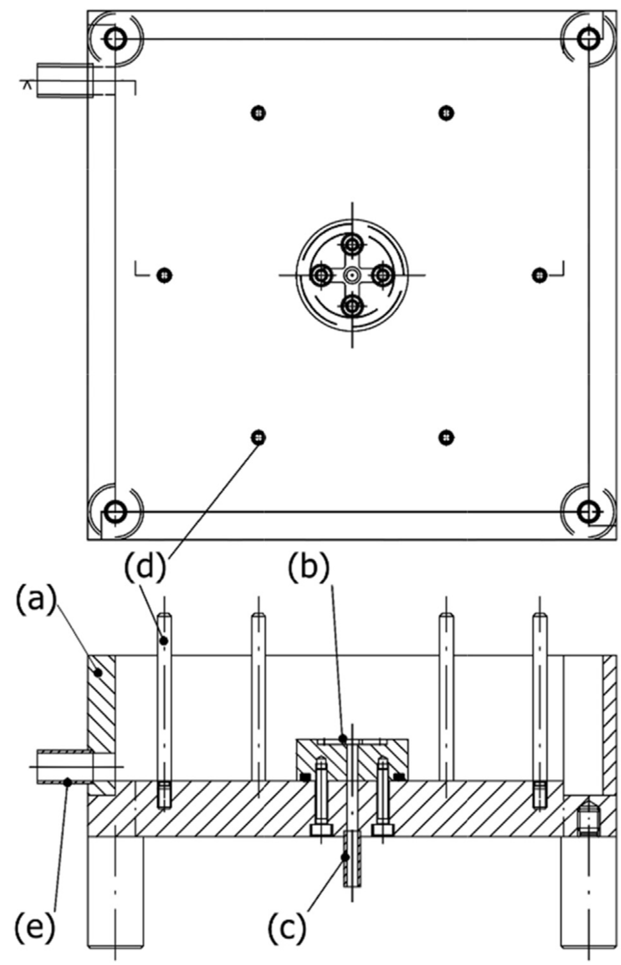

Fig. 2. The design of our set-up: (a) main body, (b) wafer chuck, (c) vacuum pump outlet, (d) alignment columns, (e) liquid in/out.

2.3. The wafer design

Knowing the wafer design, the amount of chips, and their position on the wafer, are the important parameters for determining the further transfer steps. In our case, see Fig. 3a, we have

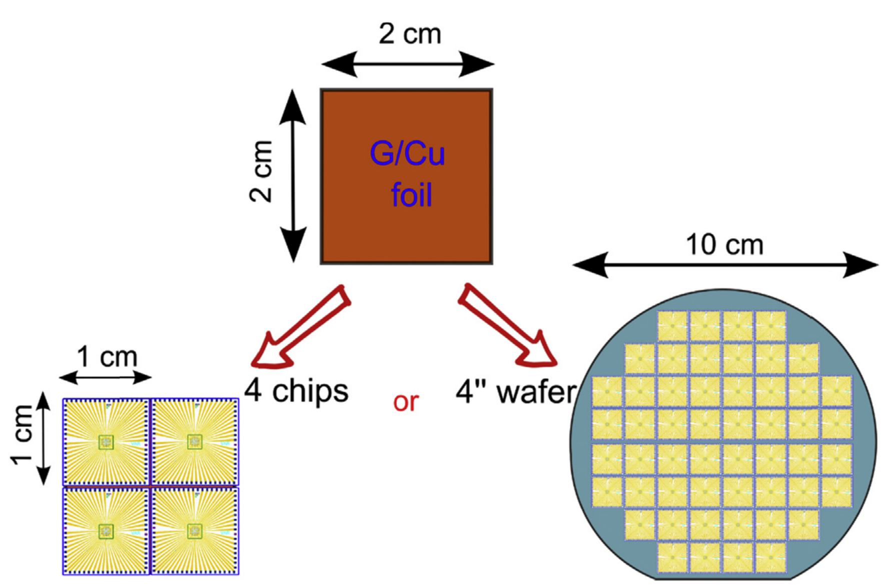

Fig. 1. The advantage of the proposed method: from a small piece of the graphene foil (2 cm × 2 cm) we can obtain 52 chips on one wafer (4-inch); instead of 4 chips yielded by the standard fishing method. (A color version of this figure can be viewed online.)