CARBIDE BONDED GRAPHENE COATING ON SILICON MOLD FOR PRECISION GLASS MOLDING

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ABSTRACT
The severe adhesion between silicon and glass has limited its application as mold material in precision glass molding. In this paper, a novel coating approach to create non-stick silicon mold for glass molding was introduced by using carbide-bonded graphene, a two dimensional material with a patterned atomic structure. A graphene coated silicon mold was fabricated using a coating process developed in house. Characterizations of coating reveal extraordinary mechanical properties. A glass sample with micro wells was successfully fabricated using a graphene coated silicon mold. This research demonstrated the functionality of the graphene coating. This newly developed process enables the use of silicon as mold material to fabricated sophisticated structures and high precision dimensions on glass which were not previously available. The result from this study will greatly improve precision glass molding.

1. INTRODUCTION
Silicon is the most widely used material in micro fabrication industry because of its excellent material properties, availability and low cost [1]. A great variety of features and structures have been fabricated on silicon and some of which are ideal shapes for the mold in precision glass molding [2]. However, silicon cannot work directly as mold material due to its severe adhesion to glass at elevated temperature. This adhesion is usually caused by anodic bonding or other chemical reactions [3]. It will be beneficial to eliminate the adhesion such that silicon with fine features can be used as mold for precision glass molding. Carbide bounded graphene coating is an ideal solution to solve this problem. This material can isolate the direct bonding between glass and silicon. Graphene is a two dimensional material with a regular hexagonal pattern atomic structure. A recent discovered coating process enables the building of a strong carbide-bonded graphene coating as protective layer on silicon substrate, which provides the graphene coated silicon mold with many extraordinary properties.

2. CARBIDE BONDED GRAPHENE COATING
The approach to obtaining carbide-bonded graphene coating on silicon substrate is illustrated in FIGURE 1 [4]. A silicon wafer, a piece of GP-SO₃H nanopaper and a high-temperature silicone rubber were pre-placed inside a quartz tube. The temperature of the quartz tube was quickly increased from room temperature to 500 °C under vacuum for 30 minutes then to 1,000 °C in nitrogen for another 20 minutes. Upon heating, the silicone rubber was thermally decomposed at elevated temperatures to form Si- or SiO- radicals. Simultaneously, graphene sheets exfoliated from the nanopaper. Most of reactive sites such as carbon radicals would react with reactive silicon species to construct C-SI or C-O-SI bonds. At high temperatures, the substrate surface was activated to produce –Si or –SiO- active groups. As the vacuum was released, the graphene sheets were sequentially deposited onto the substrate, ensuring the formation of robust silicon carbide, silicon oxycarbide, and oxycarbide covalent bonds between the graphene nanosheets and the substrate and among graphene nanosheets.

FIGURE 1. Mechanism of the coating of graphene nanosheets on the Silicon substrate surface.

The coated sample was washed with water and acetone to remove ash on the coated surface, followed by drying in vacuum oven at 100 °C overnight.
FIGURE 2. (a) Young’s modulus and Hertzian hardness of graphene coating on silicon wafer (grey) and silicon wafer (white), smaller scratch mark is shown on (b) carbide-bonded graphene coating on silicon wafer than (c) silicon wafer. The carbide-bonded graphene coatings on silicon substrate provide a unique combination of many outstanding properties. As shown in FIGURE 2 (A), the Young’s modulus and Hertzian hardness of the thin graphene coating (~45 nm) on silicon wafer is about 4 times over those of silicon wafer itself. The friction coefficient of the same coating is only 0.029, which is much lower than that of silicon wafer substrate (0.076). Furthermore, as shown in figure 2 (b) and (c), the coating also exhibits great anti-scratch performance.

3. GLASS MOLDING EXPERIMENTS
A few preliminary molding tests have been carried out for the performance of carbide-bonded graphene coating. FIGURE 3 shows the glass molding results using an uncoated silicon wafer and a carbide-bonded graphene coated silicon wafer as molds. P-LASF4 glass was used and the molding temperature was 640°C in both cases. As compared in FIGURE 3, the molded glass and silicon were broken because of the adhesion caused thermal stresses while the silicon with carbide-bonded graphene coated mold was successfully used to compression mold the glass part without any contamination and mold/part failure.

In another test, a silicon mold with micron pillars was coated with carbide-bonded graphene coating. The pillars have a diameter of about 6 µm and height of 2.8 µm.

FIGURE 4. A Molded micro wells surface on glass by using graphene coated silicon mold.

After molding, as shown in FIGURE 3 the micro wells were successfully duplicated on the glass substrate. The depth of the micro wells is about 0.7 µm. Despite of depth discrepancy, features on mold were successfully transferred to glass without adhesion problem. For industrial applications the glass molding control parameters can be optimized.

CONCLUSION
The research reported for the first time of using the carbide-bonded graphene coating as an effective and high performance coating material for precision glass molding. By applying the carbide-bonded graphene coating on silicon molds, micro scale glass components can be manufactured in high volume because these molds shows non-adhesion, low friction high temperature stability and low cost properties.

REFERENCES