Large scale structures in chemical vapor deposition-grown graphene on Ni thin films

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Abstract

Multi-layer graphene flakes with superior properties can be produced by chemical vapor deposition (CVD) on Ni substrates over large areas. We report a detailed investigation of lateral structures corresponding to correlated variations in Ni roughness and multilayer graphene thickness uniformity that may form under certain conditions over the wafer with large (mm to cm) feature size. Investigating these structures is important for understanding the interplay between carbon diffusion, segregation, metal grain formation and its role on graphene growth. In this study, we investigated such structures formed after CVD graphene growth on 200 nm Ni thin films on SiO₂ (300 nm)/Si substrates by optical microscopy, atomic force microscopy, scanning electron microscopy and Raman microscopy. Our findings showed large-scale Voronoi-like structures featuring roughness variations in the Ni film correlated with the thickness distribution of the graphene multilayers. Ni recrystallization during the CVD process plays a pivotal role in forming these structures. Similar roughness-related structures do not form without a source of carbon (methane) present during the process, which shows that carbon diffusion/segregation and Ni recrystallization are mutually dependent.

1. Introduction

Graphene has attracted a great amount of attention due to its superior mechanical, chemical and electrical properties. In addition to monolayer graphene, multiple graphene layers are of significant technological interest. For example, bilayer graphene is interesting since gating produces a band gap, while tri-layer (and more) graphene also shows interesting electronic properties for certain stacking configurations [1]. As summarized in Ref. [2], multiple graphene layers offer promise as electrode materials for energy storage devices such as Li-ion batteries and supercapacitors [3, 4] due to their high electrical and thermal conductivity [5, 6], large surface area (2675 m²/g) [7], and strong mechanical strength (~1 TPa) [8]. Other graphene applications include transparent conducting films [9] and sensors [10]. In order to be able to produce graphene for a dedicated application it is very important that the growth is as well-controlled as possible. In this work, we investigate mechanisms that may lead to large scale (mm to cm) non-uniformity of multilayer graphene grown on Ni thin films.

Different methods have been used to synthesize (multiple) graphene layers, amongst which chemical vapor deposition (CVD) has been considered as a suitable technique for large area production [11, 12]. In CVD, a metallic catalyst is often used to lower the dissociation temperature of the carbon containing precursors, such as methane. For production of multiple graphene layers (sacificial) Ni thin films are widely used due to the high carbon solubility in Ni [13-16].

The graphene growth mechanism on Ni catalysts is proposed to include three main steps: i) catalytic decomposition of precursor molecules to produce C atoms, ii) carbon dissolution into the metal at high temperatures and iii) crystallization of carbon atoms onto the metal surface to form graphene [17-20]. The graphene crystallization step on Ni is a dynamic process taking place in three temperature regimes: i) at high temperature (>1180 K), the carbon depth-distribution is uniform and the extent of segregation is small; ii) in a wide intermediate temperature range (~1065–1180 K) the carbon surface coverage is constant and a segregated phase exists, which can be interpreted as a single segregated monolayer; iii) precipitation due to decreased C solubility at low temperature (<1065 K), resulting in multilayers [20].

It is known that the impurities in transition metals are prone to segregate at grain boundaries [20]. Considering graphene growth, grain boundaries can act as sink points of carbon, pumping out the carbon...
atoms from the surrounding grains to supply the carbon demand for the growth of multiple graphene layers [17]. Graphene layers nucleate with the aid of a large number of nickel atomic steps. Once a particular site is triggered and activated, it can promote carbon segregation and precipitation, starting the nucleation of graphene. Following the nucleation, graphene layers grow laterally from a particular nucleation site and cover the nickel surface, possibly crossing “inactive” grain boundaries where there is insufficient surface curvature [17]. As more carbon is drained from a grain boundary, the number of graphene layers increases [14]. Since grain boundaries act as nucleation sites for graphene growth and play an important role in determining the number of graphene layers as well as the uniformity of the coverage [14], the morphology of the Ni film has a major effect on the graphene growth process. At process temperatures as high as those used in CVD graphene growth, significant evolution of the film morphology occurs due to recrystallization. Recrystallization has a prominent effect on the morphology as it reorganizes the surface by grain growth, determining the grain size and grain boundary density. The roughness of the surface increases by recrystallization due to the formation of grains of different heights and thermal grooves [21]. The walls of the grain boundaries, and therefore the thermal grooves, have an important effect on graphene nucleation. In our work we observe the results of recrystallization on the morphology of the film not only on μm but also on cm length scales.

CVD-grown graphene layers can be produced with high quality and their morphology at rather small length scales (from microns to mm) is well understood [15]. However, when investigated at the wafer scale, non-uniformities may occur forming morphological structures in the Ni/graphene layers that extend over several mm or even cm. It is important that these structures are understood, since the processes involved in their formation may affect wafer scale uniformity for mass production of graphene. In this study, we investigated such structures observed on 100 mm (four inch) wafers after CVD growth of graphene on Ni thin films. We will show that the interplay between Ni recrystallization, carbon uptake in the Ni thin film, and the growth of graphene on the Ni surface, may lead to remarkable patterns with feature sizes of several mm. Essential in understanding the formation of these structures is the process of Ni recrystallization affected by temperature, strain and the presence of carbon.

2. Experimental

Multiple graphene layers were grown on 185 nm polycrystalline Ni thin films on Si substrates with 300 nm thermally grown SiO₂. Ni thin films were electron beam deposited at room temperature and transferred into a cold wall CVD chamber without breaking the vacuum. The Ni thin films were heated to 950 °C in H₂ atmosphere (100 Pa) with a heating rate of 1 °C s⁻¹. As soon as the process temperature of 950 °C was reached, the CH₄ flow (10 sccm) was added to the H₂ flow (200 sccm) for 10 min, while maintaining a process pressure of 100 Pa. Afterwards, the CH₄ flow was stopped and the wafer was cooled down to 400 °C in H₂ atmosphere (200 sccm) with the same cooling rate as used for heating. The total process pressure remained at 100 Pa until the wafer was cooled down to 400 °C. The wafer was further cooled in Ar (500 Pa). The surface of the Ni films, after graphene growth by the above explained CVD process, is investigated via optical microscopy, atomic force microscopy (AFM), scanning electron microscopy (SEM) and Raman microscopy. AFM was performed in tapping mode using a Bruker Dimension FastScan AFM. SEM images were acquired with a FEI Nova 600 Nanolab Dualbeam SEM/FIB, operating voltage 500 V – 30 kV while SEM and electron backscatter diffraction (EBSD) were performed with a Zeiss MERLIN HR-SEM, operating voltage 20 V – 30 kV. Raman microscope images were obtained with a WITec combined alpha300R/300A/300S system, using a 532 nm laser with 2 mW laser power and with a step size of 1 μm. A 100 × objective lens was used and all Raman spectra were calibrated using a silicon wafer. Measurements were performed in air.

3. Results and discussion

Fig. 1 shows optical microscope images of the Ni(185 nm)/SiO₂(300 nm)/Si substrates after multilayer graphene growth by the CVD process explained above. The images are contrast enhanced for better visualization. Fig. 1.a shows about a quarter of a 100 mm wafer, the center being the right top corner of the image. The image shows cell-like structures (hereafter simply called “cells”), bordered by dark lines. In a control experiment, in which the temperature and H₂/Ar gas flow profile was the same but no methane was supplied, the cell formation was not observed, showing that carbon uptake in the Ni film plays a crucial role in the formation of these structures. It is worth noting that the cell structures can be suppressed by varying the deposition conditions (pressure, temperature, gas mixture, timing of the process steps, etc.). We limit the scope of this work, however, to the analysis of samples produced using the conditions specified above.

Some of the cells include a circular shade in the central area (Fig. 1.a,b). In some cases, the circular areas have a particle in the center. Such particles are clearly visible in zoomed-in microscope images and SEM images (not shown), one is visible here as a black dot in Fig. 1.b-e. We used this particle as a position marker in this work, enabling studies of the same region on the wafer by different imaging and analysis techniques. The cells become smaller in size towards the edge of the wafer (region with the scale bar). This might be attributed
to gradients in the temperature and gas flow/pressure during the CVD process. Fig. 1.b-e show subsequent magnifications of the regions marked with the red rectangular frame on the previous image. Although the dark lines bordering the cell-like structures can be seen easily in low magnification images, they become indistinguishable with further zooming in: It can be seen in Fig. 1.e, in which individual multilayer graphene flakes are visible as dark specks on a lighter background, that the lines are not visible anymore. Therefore these dark contrast features cannot be attributed to an increased areal density of graphene flakes that are sufficiently thick to be visible under an optical microscope. In addition, regions of dark contrast are converted into bright contrast when changing the microscope illumination from perpendicular (Köhler) to oblique. These observations indicate that scattering of light, affected by the incident angle of the illumination as well as the focal length of the lens, is responsible for the contrast observed in the images.

Fig. 2 shows the zoomed-in section marked with the red rectangular frame in Fig. 1.d. In Fig. 2.a the optical microscope image is overlaid with the root mean square (RMS) roughness map of the same area. The roughness map was obtained by calculating the average RMS roughness values of 30 × 30 μm² AFM scans stitched together to form a large area scan. The map reveals that the RMS roughness varies between 12 and 20 nm. This roughness is due to the grainy structure of the Ni film, the presence of graphene flakes on the surface has a negligible contribution. Fig. 2.b shows an overlay of both the SEM image (acceleration voltage 10 kV) and the roughness map with the optical microscope image. The lines can be followed both on the optical microscope image and the SEM image. It can clearly be seen in Fig. 2.a and Fig. 2.b that the roughness variation matches very well with the pattern of the lines outlining the cell-like structures, and with the darker shade around the particle at the center of the cell. This shows that the optical contrast is correlated to the roughness of the film, consistent with the observation that scattering of light strongly affected the optical images. We point out that similar patterns as discussed here were observed with optical microscopy in an earlier study, and were attributed to the bare Ni surface due to hydrogen etching [15]. However, our findings show that graphene flakes are present everywhere on the surface.

Fig. 3.a shows SEM images of another location on the same wafer where cell-like structures bordered with dark lines are visible. Fig. 3.b shows a zoomed in image of the region marked with the red rectangular frame on Fig. 3.a, whereas Fig. 3.c and Fig. 3.d are further zooms of the regions marked with black rectangular frames as c and d, respectively in Fig. 3.b. The SEM acceleration voltage in Fig. 3.a and Fig. 3.b was 10 kV, while in Fig. 3.c and Fig. 3.d it was 15 kV. Multilayer graphene flakes appear as grey/black patches. The dependence of SEM contrast on the number of layers in multilayer graphene samples on various substrates has been addressed previously [22-25] and has been shown to be sensitive to the thickness of graphene multilayers. Important contributing factors to the SEM contrast differences are thickness dependent work function variations [22], and attenuation of secondary electrons originating from the substrate [24, 25].

The dark SEM contrast on the line can be attributed to the presence of, on average, thicker graphene layers on the line region. The bright areas in Fig. 3.c (away from the line) are indicative of Ni surface covered with a thinner or no graphene layer. As pointed out previously, no significant difference is observed in the areal density on/off the lines of the thickest (darkest) graphene flakes, that can also be seen as dark specks in the enhanced contrast optical microscope images shown in Fig. 2. Rather, the coverage of multilayer graphene with intermediate thickness appears to be increased on the lines bordering the cell structures, resulting in a more homogeneous coverage.

We investigated this issue further with Raman microscopy. Fig. 4.c shows a section of the overlay in Fig. 2 of the optical microscope image with the RMS roughness map, zoomed-in on a region including both a section of a high-roughness ‘line’ (green color) and the smoother region (red color) between the central area and the line. The upper and lower black square frames in Fig. 4.c, marked as “a” and “b” and positioned off and on the line, respectively, are mapped with Raman microscopy. Fig. 4.a and Fig. 4.b show the respective Raman maps of integrated intensity of the 2D peak region (2550–2840 cm⁻¹). The shapes of the thickest flakes can be recognized in both the optical microscope image and the Raman maps. Fig. 4.d is a comparison of the Raman measurements on the points marked with blue dots in Fig. 4.a (red) and Fig. 4.b (black). In Fig. 4.d, it can be seen that in both regions (on and away from the rough line), the D peak (1350 cm⁻¹) corresponding to the defects on graphene layers is invisible, showing that the graphene quality is high on both regions. The intensity of the G peak (1583 cm⁻¹) compared to that of the 2D peak (2710 cm⁻¹) indicates that both flakes are more than 5 layers thick.

The Raman maps in Fig. 4.a and Fig. 4.b do not show any clear differences that can be related to a difference in graphene coverage on or off the line features, as suggested by the contrast differences observed in SEM images. A more detailed, statistical analysis of the Raman maps is necessary. First, cluster analysis of the Raman data is performed, using a farthest-point clustering algorithm [26] to be able to discriminate between points in the Raman map with significantly different multilayer graphene thickness/coverage. The results are used to exclude the thickest flakes (which show similar characteristics in both regions) from further statistical analysis. We exclude these thickest flakes since they appear to be randomly distributed over the surface and hence are not correlated with any large-scale features, as pointed out previously, e.g. in the discussion of Figs. 1 and 3. Subsequently, maps are generated of the 2D/G peak intensity ratio (based on integrals of the corresponding regions in the Raman spectra), which is a measure of the thickness of multilayer graphene (larger 2D/G ratios correspond to thinner multilayer graphene), and histograms of the 2D/G ratio distributions are computed (see Fig. 5.a and Fig. 5.b). The so-obtained histograms show an approximately symmetric distribution of the 2D/G peak intensity ratio for the region on the high-roughness line, while the distribution is asymmetric with a higher yield towards lower 2D/G values for the region off the line. Similar measurements and analysis performed on a multitude of regions on and off a different line feature showed qualitatively similar results (see Fig. 5.c-e). The comparatively
higher abundance of higher 2D/G ratios (thinner multilayer graphene) for the region on the line feature and the more symmetric, Gaussian-like distribution of 2D/G ratios there is consistent with the contrast differences observed in the SEM images: Both are indicative of a more homogeneous graphene thickness distribution on the lines.

The grainy structure of the Ni film supporting the multilayer graphene can be observed in SEM images (Fig. 3.c and Fig. 3.d). We investigated the Ni grain structure in detail using EBSD measurements, see Fig. 6, a SEM-based technique that allows for probing of the crystallographic microstructure of a sample using analysis of Kikuchi bands. Fig. 6 shows SEM images and EBSD inverse pole figure (IPF) maps of a region of the sample containing a border between two cells, visible as a dark vertical line in Fig. 6.a. The IPF maps reveal a strong out-of-plane (111) texture (Fig. 6.c, inset, almost entirely blue) and a random in-plane orientation of crystalline grains (Fig. 6.c and d). A comparison of SEM images and IPF maps shows a clear correlation between features related to the grain structure (Fig. 6.e and f). The line structure visible in (a) does not appear to be correlated with any particular in-plane orientation pattern of the Ni grains in (c). Analysis of the grain size distribution, using thresholding of EBSD maps, reveals no significant variation of the grain size on versus off the line structures. Grain size analysis performed on four different locations showed that the average size of Ni grains on top of the lines is at most 1.09 times that of grains located away from the lines (Fig. 6.g and h), a small difference compared to the large variation in grain size (Fig. 6.i).

The variation in roughness can be related to the interplay between recrystallization of the Ni film and carbon redistribution in the film, as we discuss below. The high temperature treatment during the graphene growth has a significant effect on the film morphology as it leads to the recrystallization of the film (as-deposited Ni films exhibit much smaller grain sizes) [21]. As a result of this recrystallization, the Ni film exhibits grains that are large compared to the film thickness (average grain size related to...
≈ 2 µm², see Fig. 6.i, film thickness 185 nm) and a strong (111) texture out-of-plane (see Fig. 5). The latter can be understood from the fact that the close-packed 111 face of the fcc Ni crystal has the lowest surface energy. In addition to high temperature, stress resulting from the different thermal expansion coefficients of the substrate and the thin film plays an important role. The role of stress on the recrystallization of bulk materials and thin films is well documented[27]. That (local variation of) stress can indeed play a role in the formation of the cell-

Fig. 5. Raman maps (insets) and histograms of the 2D/G peak intensity ratios for the regions (a) off and (b) on the line feature. The thickest multilayer graphene flakes (white areas in the maps) are excluded based on cluster analysis of the Raman data. (c) Microscope image showing a diagonal high-roughness line feature, taken with oblique illumination such that high roughness areas appear bright. The colored frames (approximately 50 × 50 µm) indicate the positions where Raman maps were recorded. (d) Histograms of the 2D/G peak intensity ratios extracted from the Raman maps, for the six regions off the line in corresponding colors. The histograms were normalized to the maximum height and the mean 2D/G ratio was subtracted, yielding approximately aligned differential 2D/G ratio histograms. (e) Similar histograms for the five regions on the line, again in corresponding colors.

Fig. 6. (a) SEM image showing multilayer graphene flakes (darker contrast corresponding to a larger number of layers) and a dark vertical line (cell border). (b) Higher resolution SEM image of the region marked with the red rectangular frame in (a), with yellow dashed lines indicating the borders of the dark line. (c) EBSP inverse pole figure (IPF) map, corresponding to the region marked with the red rectangular frame in (b), showing the alignment of the crystallographic axes of Ni grains along the vertical in-plane axis (IPF color key shown in (d)). The inset (lower left corner) shows the out-of-plane IPF map of the same region, which reveals a (111) out-of-plane texture. The black dashed lines indicate the position of the dark vertical line visible in (a). (d) Zoomed-in IPF map of the region marked with the red rectangular frame in (c), in which the in-plane orientation of individual grains can be observed. (e) SEM image and (f) EBSP inverse pole figure (IPF) map of the same region of a multilayer graphene on Ni (185 nm film) sample. The IPF map in (b) shows the orientation of Ni grains relative to the vertical in-plane axis, with the color key shown in the inset. Features in (e) can be correlated to crystalline grains in (f), for example a grain near the top right corners of both panels is indicated by the letter “x”.

(g) Comparison of the average grain area on (red filled circles) versus off (blue filled squares) lines bordering cells. Grain size analysis was performed using thresholding of EBSP maps on four locations exhibiting a clearly identifiable line structure, corresponding to experiment numbers 0 - 3 on the horizontal axis. Locations “on” or “off” a line were determined from the contrast observed in SEM images, based on which the EBSP maps were segmented into regions using straight lines. Data points for the “on” measurements received a small horizontal offset for clarity. The “error bars” are equal to the average deviation of the grain area distributions. Note that these do not indicate the error in the determination of the average grain area, but rather indicate the spread of the distribution. (h) Same as (g), however excluding grains that intersected the boundaries of the measurement region (and hence are not entirely identifiable) or boundaries between segmented regions (residing both “on” and “off” a line structure). (i) Histogram of the area distribution of Ni grains (100 bins, bin size 1 µm²), obtained from a thresholded EBSP map. The histogram represents the grain size distribution on top of the line structure shown in (a), i.e. between the dashed lines shown in the SEM image and EBSP map. It is representative of grain size distributions elsewhere on the same sample: analysis performed on other regions yielded similar histograms.
like structures we observe is clearly illustrated by Fig. 7 showing an optical microscope image of another Ni/graphene sample fabricated under similar conditions. The black dot in the center of the microscope image in Fig. 7.a turns out to be a dome-like structure upon closer inspection with a higher magnification (Fig. 7.b), where presumably a gas bubble is formed in/under the Ni film, causing additional stress by pushing the film upward. We base this conclusion on the approximately hemispherical shape of the protrusion, in contrast to the irregular shape of (dust or carbon) particles, and the observation of a grainy appearance from base to apex (visible upon adjusting focus), similar to the Ni surface elsewhere. Around the central dome structure, a roughly circular region of the Ni film in Fig. 7.a shows similar optical contrast, while it is broken up in a multitude of much smaller cells outside this circular region. This might indicate a relation between the formation (and expansion) of the cells and the local stress in the Ni film.

For the remaining discussion, some microscopic mechanisms behind recrystallization need clarification first. During growth of the polycrystalline Ni film, energy is stored in the form of structural defects such as dislocations. This energy can be released mainly by recrystallization and grain growth [28, 29]. Recrystallization occurs by the formation and migration of high angle grain boundaries that exhibit a 10°–15° misorientation or larger with respect to (at least part of) their surroundings [30], of which the mobility is high compared to that of low angle grain boundaries [31]. As a result of this mobility difference, only grains that are highly misoriented can grow quickly [32]. When high angle grain boundaries are no longer present in the neighborhood of a growing grain, the grain growth stops, which is known as orientation pinning.

The migration rate of grain boundaries during recrystallization depends also on the concentration of impurities [28, 33, 34]. In the CVD graphene growth process, after methane is supplied, recrystallization proceeds simultaneously with methane dissociation, carbon uptake in the Ni thin film, and graphene growth. Carbon atoms diffuse relatively fast along grain boundaries, which therefore act as carbon sinks during graphene precipitation. It has been reported that even when carbon is uniformly distributed in the Ni thin film by ion implantation, the carbon concentration is redistributed and becomes inhomogeneous after graphene formation at high temperature [17, 18]. Impurities dissolved in metals can retard the motion of grain boundaries [34]. It is important to note that we observe the cell patterns only when methane is present during the CVD process, which suggests that different crystallization rates owing to the gradients in carbon concentration in the film are essential. When the carbon content is sufficiently high, the excess carbon can lead to the formation of carbides [35, 36], which might be related to the formation of particles (Fig. 1). It is known that particles may act as nucleation sites for recrystallization [33], consistent with our observation that whenever we find particles, they are located at the centers of the cells.

Another factor that plays a role on the roughness of the surface during recrystallization is the formation of thermal grooves [21], which form mainly by surface diffusion of Ni atoms to equalize the tensions of the film surface and the grain boundary [37-39]. As the depth and corresponding curvature of the groove increases beyond a certain threshold, the grain boundary will no longer be able to migrate [38, 40], and further deepening of the groove will result in increased roughness.

Interestingly, the cell patterns in our samples can be loosely interpreted via Voronoi pattern formation. In some regions, reconstruction of the patterns by Voronoi tessellation gives a rather close match. Voronoi tessellation partitions a plane into cells using a discrete set of seed points, with each cell being defined by the closest distances to a certain seed. It therefore applies to the study of any structure that involves seeds (or nuclei) from which it has evolved. For example, in material science, it has been used to study the structure of metallic composites, and other such aggregates on the microscopic scale [41, 42], as well as island formation at the initial stages of growth of metal thin films [43, 44]. In Fig. 8.b the red lines represent a Voronoi pattern constructed by taking the approximate central points of the dark circles as seeds. It can be seen that the pattern and the image match nicely.

In the present case, the ability to reconstruct the cell pattern (at least partially) by Voronoi tessellation suggests that the cells have evolved from a central point, presumably a location featuring accelerated recrystallization, for example due to high local stress.

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Fig. 7. Optical microscope image of (a) a large roughly circular cell with similar contrast with a black dot in the center, with a multitude of smaller cells outside this circular region. (b) Zoomed-in image of the black dot at the center of (a), showing a dome-like structure where presumably a gas bubble is formed in/under the Ni film causing additional stress. Note that the dome apex is in focus, while the surrounding surface area is out of focus due to the considerable height of the dome.

Fig. 8. (a) Contrast-enhanced optical microscope image of Ni thin film after CVD growth of multilayer graphene. The red lines in (b) represent a Voronoi tessellation generated using the red dots as seeds.
(exemplifying any distortion more pronounced the longer a grain boundary has stayed immobile and note that thermal grooving might play a pivotal role, since it becomes)

4. Conclusions

After the deposition of multilayer graphene on Ni thin films by CVD, large scale Voronoi-like structures in the Ni/graphene film morphology were observed extending over several mm (or even cm). The structures correspond to correlated lateral variations in Ni roughness and graphene thickness uniformity: on the borders of the cells the Ni is rougher, and the graphene thickness distribution more homogeneous.

Control experiments showed that similar, roughness-related structures do not form in Ni films exposed to a similar ‘CVD’ treatment without methane, hence they only form when carbon is present in/on the Ni. The structures were investigated by optical microscopy, AFM, SEM and Raman microscopy, which showed that they are closely related to roughness variations. The roughness variations might be attributed to differences in recrystallization rate due to several factors such as inhomo- geneous carbon concentration, orientation pinning and thermal grooving. The cell structure can be partially reconstructed by Voronoi tessellation, suggesting that it evolves from a distribution of seed points. Our work provides insight into the interplay between carbon diffusion, segregation, metal grain formation and its role on graphene growth, relevant for large-area CVD growth of graphene on Ni.

CRediT author statement

DA carried out sample fabrication, measurements and analysis, and co-wrote the paper with MdJ. MdJ carried out additional data collection. JGMS assisted in sample fabrication and clean room work. MdJ, AK, SK, and DA designed the experiments. DG provided important suggestions for further experiments and analysis. All authors provided ideas and helped to write the paper.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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