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Characterization of Diamond-like-carbon Thin Film Depositions in Conjunction with High Power Impulse Magnetron Sputtering and Kick-pulse

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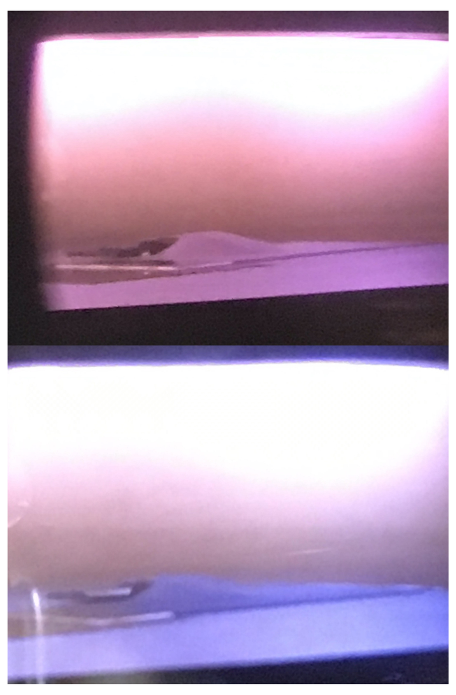
Abstract

Diamond-like-carbon thin films were deposited on silicon wafers while operated under High-Power Impulse Magnetron Sputtering (HiPIMS). Testing was performed using HiPIMS waveforms both with and without an additional reverse polarity kick-pulse. Two primary experiments were designed. The first was direct deposition onto a silicon wafer. This was analyzed with Raman spectroscopy, AFM, and profilometry. This was intended to characterize the effect of HiPIMS operation and addition of the kick-pulse on the level of diamond bond formation. The results of single wavelength Raman spectroscopy were inconclusive and necessitate the use of multiple-wavelength Raman spectroscopy. Tensile strength, modified by the thin film, will be investigated in the second experiment. The first data point has yet to be taken and further investigation is needed. Electron microscope images were taken of the films and the smoothness was calculated. The Langmuir traces of different kick pulses were taken as well.

Background

Plasma Sputtering

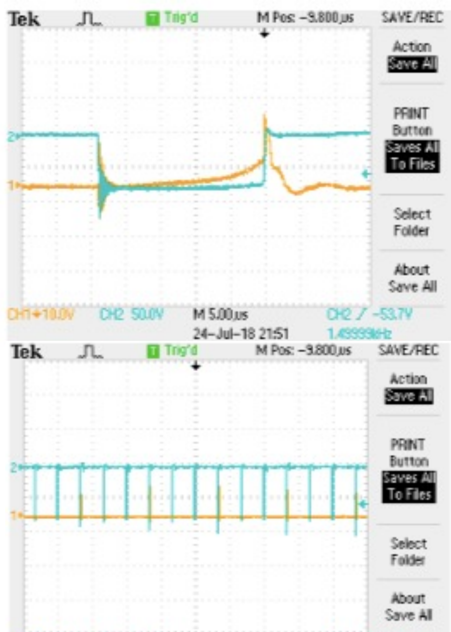
Plasmas are frequently used in physical vapor deposition often through a process of plasma sputtering, or sputter deposition. In this case, a technique called magnetron sputtering was used, where a gaseous plasma is excited in a central region of a vacuum chamber using a magnetron. When an electric field is established and current passed through, energetic ions are created in the plasma and bombard against a material target (in our case, a disc of carbon). The bombarded atoms from the target are isotopically dispersed onto a substrate material, where coating occurs. It is important to distinguish this terminology; the "target" refers to the material supplying the ions for bombardment and the "substrate" is the receiving specimen. The electrons are confined inside the space with a magnetic field, so early ionization is maximized and the density of the deposited film is greater as there are fewer gaseous atoms laid into the film foundation. Furthermore, with the addition of HiPIMS, film density is improved.



The top is an image of our sputter gun striking a primarily argon plasma with DC. The image below it is the same sputter gun combined with the HiPIMS signal. The blueness is an effect of the increased degree of self sputtering of the carbon target.

HiPIMS

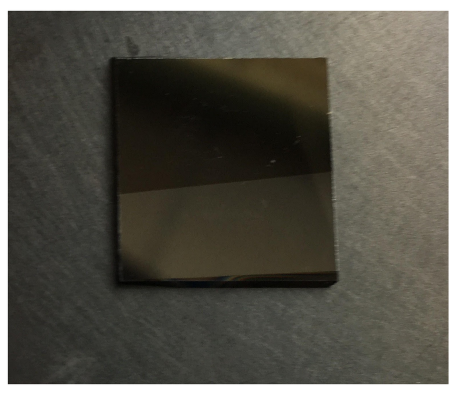
A low to medium frequency succession of high power pulses can be used to excite the plasma instead of conventional direct current. The pulse is in the microsecond range and the frequency can be widely adjusted between 50 HZ and 2500 HZ. This type of modulation affects the plasma density, ion fraction, smoothness, deposition rates, self sputtering, and possibly several surface-chemical-bonding properties. [1]



An image of the an oscilloscope trace of the HiPIMS signal. Blue is voltage and yellow is current. The top image is a single pulse and the bottom is a series of pulses.

Diamond-like-carbon

Diamond-like carbon (DLC) is a form of carbon-composite material that exhibits the physical characteristics of diamond (an allotrope of carbon, like graphite). There are seven possible arrangements of crystal lattice in DLCs, exhibiting different levels of durability. It is not uncommon to coat a material with different orientations of DLC from the target carbon. This coating enables a high electrical resistivity, ideal for electronic material coatings. Other beneficial properties of DLC include higher corrosion resistance, levels of substrate adhesion, hardness, and durability, as well as a dense crystalline structure. Applications of DLC extend into hard-disks, metallurgy, semiconductor processing, and various automotive industry practices. [2]



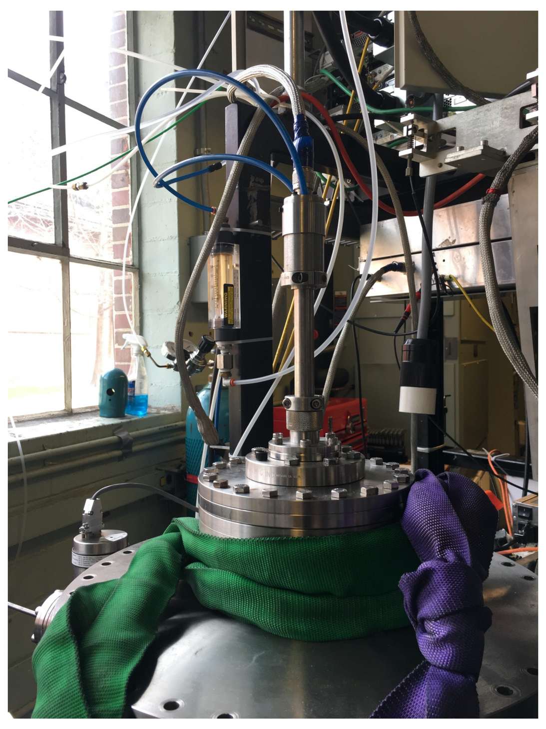
A silicon wafer sample with a DLC film deposited on the top half of it.

Experimental Setup

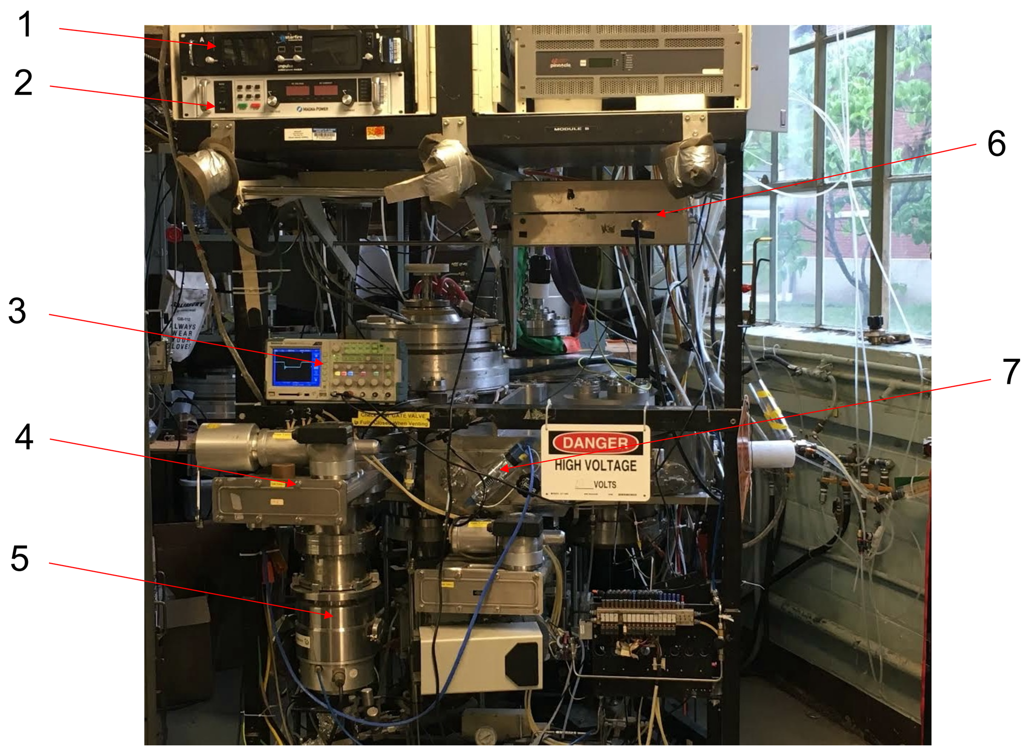
The primary experiment uses a small 1.5cm x 1.5cm silicon sample centered approximately 5 cm under the center of a Lesker four inch magnetron gun. The magnetron is fitted with a carbon target and samples are exposed to the plasma for 13 – 15 minutes. The secondary experiment investigating the DLC deposition on tensile strength used a 1cm x 3cm silicon wafer sandwich between two small wafers to have it floating above the platform. These experiments will be run for approximately 15 mins. A Starfire IMPULSE power supply and a Magna-power supply were used. There are several different run parameters that have been used and will be used in future testing.

The Galaxy Chamber

The Galaxy Chamber is the vacuum chamber used for testing. Galaxy is fitted with a both a rough pump and a turbo pump to allow the chamber to attain the necessary pressures for deposition testing. Galaxy has three separate sputtering areas for simultaneous deposition runs, though only two of these testing areas were utilized. To enable simultaneous deposition processes, Galaxy can accommodate two circular magnetrons and one linear magnetron, each of which is water cooled with build in cooling lines. Galaxy sources its power from several supply units located around the chamber. The chamber can be run using conventional DC power as well as more sophisticated HiPIMS power. When running in HiPIMS mode, a special HiPIMS unit powers the magnetron, which in turn derives its power from a conventional DC supply. The galaxy chamber is also outfitted with a sample changing load lock, which allows samples to be switched without depressurization. This allows for efficient testing, cutting out tedious depressurization time. Built into the Galaxy chamber are a number of custom made instruments for data collection. Among these are a pneumatic shutter valve, which can be engaged mid-run to partially shield specimens from deposition (allowing for multiple exposure times in one testing run).



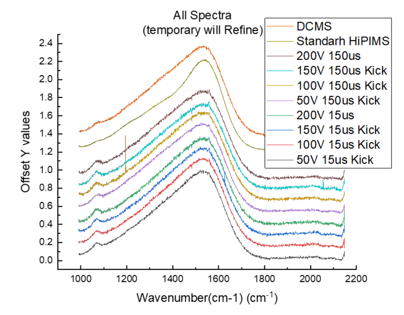
A photo of the the main deposition chamber with the four inch magnetron gun sticking out of the top.



A photo of the front of the Galaxy deposition chamber. 1. IMPULSE HiPIMS power supply 2. Magna-Power DC supply 3. Oscilloscope 4. Gate valve 5. Turbo-pump 6. Voltage and current monitoring box 7. Ion pressure gauge

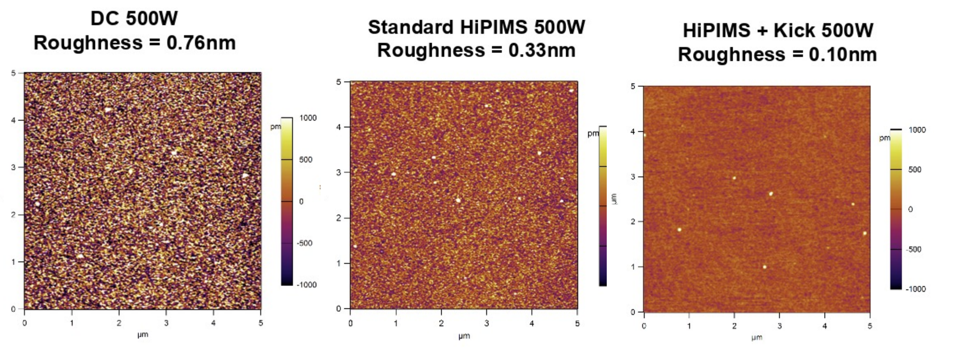
Results

Raman spectroscopy was done on the small silicon samples. The plot shows qualitative difference in the 532 nm Raman shift due to different kick pulse parameters [2]. The lack of quantitative results has motivated the use of multi-wavelength Raman spectroscopy for future samples.



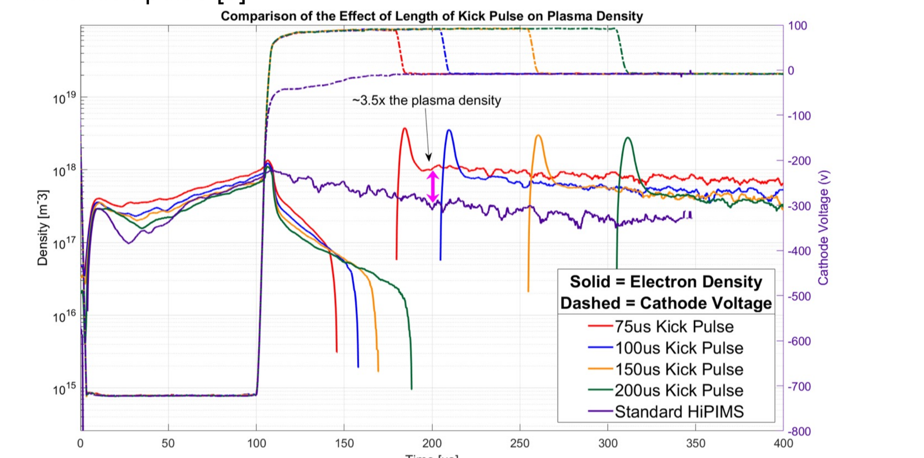
Plot of Raman Shifts for different pulse parameters [3].

The roughness of the silicon samples was measured using atomic force microscopy and was found to decrease with both HiPIMS and the HiPIMS with a tail end kick pulse.



Roughness plots of a DC discharge, standard HiPIMS discharge, and finally a HiPIMS discharge with a kick-pulse [3]

Langmuir traces of 75, 100, 150, and 200 microsecond pulses and a standard HiPIMS pulse were taken. Density calculations, using traditional theory, are majorly disrupted during the kick pulse period as the Maxwellian distribution is displaced. An increase in ions is discernable due the rapid plasma response following the pulse.



Langmuir pulse traces of different kick-pulses [3].

Conclusions and Further Work

Data from the Raman spectroscopy analysis show that using a single wavelength is not sufficient to determine the SP-3 fraction. Further work is needed to determine the effects of HiPIMS and kick pulse on the tensile strength of the DLC film. The HiIPIMS with kick-pulse increased the smoothness of the film. From here, more 1.5cm x 1.5cm with several different pulse parameters need to be taken. These will be analyzed using Raman spectroscopy with several different wavelengths. This will hopefully be more successful at determining the sp-3 fraction of the films. More samples of the longer 1cm x 3cm wafers will be taken with DC , HiPIMS , and HiPIMS + kick-pulse parameters. These will be examined further using contact profilometry and the Stoney film stress formula to determine any effects on tensile strength.

References

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[2] Knight, Diane S, Characterization of diamond films by Raman Spectroscopy, J. Mater. Res., Vol. 4, No. 2, Mar/Apr 1989

[3] DLC with iPVD through Modified High Impulse Magnetron Sputtering Ian Haehnlein, Baohua Wu,D. Eitan Barlaz, Jake McLain, Brian Jurczyk, David N. Ruzic

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