Department of Physics, Chemistry, and Biology

Master’s Thesis

Development of a Dense Diffusion Barrier Layer for Thin Film Solar Cells

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Tantalum diffusion barrier coatings were investigated as a way to improve the conversion efficiency of CIGS (copper indium gallium diselenide) solar cells. Tantalum coatings were deposited upon silicon and stainless steel foil substrates using direct current magnetron sputtering (DcMS) and high power impulse magnetron sputtering (HiPIMS). The coatings were characterized using scanning electron microscopy (SEM). Cross-sectional scanning electron micrographs revealed that the HiPIMS coatings appeared denser than the DcMS coatings.
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1 INTRODUCTION

1.1 Background

The use of photovoltaic solar technologies to generate electricity has grown considerably over the last decade due to improvements in efficiency and reduced production costs. A thin film photovoltaic technology of particular interest is the CIGS based solar cell device; it is a direct semiconductor, chalcopyrite compound material composed of copper, indium, gallium, and selenium.

CIGS solar cells are commonly fabricated using soda lime glass (SLG) as the substrate. SLG is inexpensive to produce, vacuum compatible (i.e. negligible degassing), and has a smooth surface (which is desirable for film growth). The substrate also has the added benefit of diffusing sodium into the CIGS absorber which has been shown to improve cell efficiency [1]. In the laboratory, record efficiencies of over 19% have been achieved [2]. Drawbacks to the use of SLG as a substrate are that it is bulky, fragile, and has a limited form factor; mating a CIGS absorber to such a substrate defeats the intrinsic benefits associated with this technique (e.g. thin profile and flexibility). Stainless steel (SS) foils have been investigated as a suitable alternative substrate to soda lime glass due to beneficial attributes including strength, low weight, flexibility, improved device cooling under concentration, and amenability to low cost production. With regard to the sodium diffusion benefit afforded to the SLG substrate, there are techniques used today to incorporate sodium into the absorber layer when SLG is not used [3]. However, there is one major drawback to the use of SS foils as a substrate and that is the high process temperatures (>550°C) required to synthesize the CIGS absorber layer causes the diffusion of impurities (e.g. iron) from the SS foil into the CIGS absorber; this has been shown to be detrimental to the cell efficiency [4]. Therefore, there is a need for a method to inhibit the impurity diffusion; one such method is to grow an intermediary, thin film diffusion barrier layer between the SS and CIGS absorber.
1.2 Objective
The purpose of this diploma work is to develop a thin film barrier layer which will adequately inhibit the diffusion of impurities from a stainless steel foil into a CIGS absorber layer. The film should be dense, electrically conductive, and thermodynamically stable; it should also possess good adhesion properties and be easy to synthesize.

1.3 Delimitation
This thesis is intended for individuals who possess a basic knowledge of thin film physics and scanning electron microscopy (a characterization technique). Thin film deposition techniques are treated briefly. The primary focus of this thesis is on HiPIMS (High Power Impulse Magnetron Sputtering) and the use of the technique to synthesize a high quality diffusion barrier layer.

This diploma work was performed in collaboration with industry and it was agreed that proprietary intellectual property would be omitted from this thesis. Therefore, this thesis was written with the core focus on theory and less attention given to results.
2 PHOTOVOLTAIC PERFORMANCE

2.1 Overview
In this chapter, a common metric for characterizing the performance of a CIGS photovoltaic device will be discussed. This metric is known as “dark and light $I/V$ characterization” and is presented in section 2.3.

2.2 Performance Parameters
There are four major parameters typically measured when evaluating the performance of a photovoltaic device: open circuit voltage ($V_{oc}$), short circuit current ($I_{sc}$), fill factor (FF), and conversion efficiency ($\eta$). The higher the values are for each of these parameters (up to their theoretical limits), the better the performance of the device.

The $V_{oc}$ is the difference in potential between two terminals of a device when the circuit is open and occurs when there is no current passing through the device; it is expressed in volts (V). The $I_{sc}$ is calculated when the voltage is zero and corresponds to the short circuit current when there is low impedance; it is expressed in current density (mA/cm$^2$). The FF is calculated by comparing the ratio of maximum power to theoretical power that would be output at both the $V_{oc}$ and $I_{sc}$; it is dimensionless and is typically expressed as a percentage. The $\eta$ gives the effectiveness of converting light power into electrical power (i.e. photons to electrons) and is the most quoted parameter when comparing solar photovoltaic devices; it is expressed as a percentage [5].

2.3 Dark and Light $I/V$ Characteristics
Figure 2.1 shows the current-voltage (i.e. $I/V$) characteristics of a photovoltaic solar device in the dark and under illumination.
Figure 2.1: Current-voltage (I/V) characteristic of a CIGS photovoltaic device with and without illumination [6].

Power is generated when the device operates in the fourth quadrant where current is negative and voltage is positive. The FF is of particular interest when analyzing I/V characteristics because it provides a measure of the quality of the solar cell. To calculate the FF, see Equation 1:

\[
FF = \frac{P_{\text{MAX}}}{P_T} = \frac{I_{\text{MP}} \cdot V_{\text{MP}}}{I_{\text{SC}} \cdot V_{\text{OC}}},
\]

Where: 
- \(P_{\text{MAX}}\) = maximum power point
- \(P_T\) = theoretical power point
- \(I_{\text{MP}}\) = current at \(P_{\text{MAX}}\)
- \(V_{\text{MP}}\) = voltage at \(P_{\text{MAX}}\)
- \(I_{\text{SC}}\) = short circuit current
- \(V_{\text{OC}}\) = open circuit voltage

The FF can be interpreted graphically as the ratio of the rectangular areas depicted in Figure 2.1. In essence, the FF is really a measure of how rectangular the illuminated I/V curves are in the fourth quadrant. The challenge for photovoltaic device makers is to boost the FF value by moving \(P_{\text{MAX}}\) as close to \(P_T\) as possible.
3 FILM STRESS, GRAIN BOUNDARIES, AND DIFFUSION BARRIERS

3.1 Overview

Ideally, thin film diffusion barrier materials would be structurally and intrinsically perfect but in reality this is not the case due to the formation of defects that occur during and after thin film synthesis; bulk materials also have defects but the density of defects per unit volume is considerably lower than that exhibited by thin film materials. Two thin film defects of interest to this research are intrinsic thin film stresses and grain boundaries which are discussed in sections 3.2 and 3.3. Diffusion barriers are discussed in section 3.4.

3.2 Intrinsic Thin Film Stresses

Thin films can exhibit mechanical stress that is either compressive or tensile depending on the deposition technique, the growth conditions, and the molecular structure inherent to the film material. These stresses can have a negative effect on film properties including adhesion and cracking. There are a multitude of factors which can influence whether the film stress is compressive or tensile: ion energy, pressure, substrate-to-target distance, etc. For example, the level of ion energy used to synthesize a film can result in a film with tensile stress or compressive stress (Figure 3.1).

![Schematic of how a film could behave with tensile and compressive stress.](image)

**Figure 3.1:** Schematic of how a film could behave with tensile and compressive stress.
From Figure 3.1 we can see that when using low energy ions, the ions that impact the substrate have low adatom mobility which leads to the formation of voids and shadows in the film and could result in a low packing factor (i.e. the film stress is tensile so the film wants to shrink). When using high energy ions, the ions bombard the substrate with a lot of force; the end result could be a film with a high packing factor (i.e. the film stress is compressive so the film wants to expand) [7]. Another situation that we found could lead to a film with a high packing factor is when tantalum is used as the target and argon as the working gas. This is because tantalum is a heavy element so some of the argon ions hitting the target do not sputter the target but are, instead, neutralized; the argon atom bounces off the target at cathode energy (e.g. 700 eV) and impacts the substrate with high energy resulting in a film that could have compressive stress.

In a similar way, pressure can influence the level of ion energy and neutral particle flux impacting the substrate. Higher pressures reduce the mean free path of a particle (i.e. increase collisions) which reduces the kinetic energy and results in lower energy ions. Lower pressures have the opposite effect. Substrate-to-target distance influences film stress by affecting how much ion energy reaches the film surface. For example, when using a magnetron sputtering system, the magnetron can inhibit electron mobility — leading to a voltage drop in the plasma — if the gap between the substrate and target is too small. The result is particles with lower kinetic energy impacting the substrate. The coefficient of thermal expansion can affect film stress; for example, the mismatch of thermal expansion between the thin film and the substrate may lead to residual stresses in the film. Ultimately, the aforementioned parameters (along with other factors) must be managed to reduce the total amount of stress in the film.

### 3.3 Grain Boundaries

Grain boundaries are the incomplete mating of many small single crystals — in a polycrystalline solid — which are misoriented with respect to each other; they are a planar defect that partitions areas of different crystalline orientation. At these grain boundary regions, atoms are loosely bounded. These mobile atoms cause grain boundaries to be heterogeneous regions where reactions like solid-state diffusion occur.
In bulk materials, grain boundaries are usually of minimal influence since they are less common; however, in thin films they are more prevalent and can result in grain boundary diffusion. In photovoltaic CIGS applications, grain boundary diffusion between a metal foil like stainless steel and the CIGS absorber is undesirable because of the impurities in the steel. To inhibit grain boundary diffusion, a diffusion barrier can be employed and is discussed in section 3.4.

### 3.4 Diffusion Barriers

The basic concept of a diffusion barrier is to separate two materials that have unfavorable interactions using an intermediate layer. Consider barrier layer X inserted between materials A and B (Figure 3.2).

![Figure 3.2: Schematic of a hypothetical barrier layer system.](image)

The barrier layer should satisfy the following criteria [9, 10]:

1. Material X should be a barrier to kinetic traffic between materials A and B.
2. Material X should be thermodynamically stable when in contact with materials A and B and not intermix (i.e. AX and BX should not form).
3. Material X should be easy to deposit and possess good adhesion properties.
4. Stresses in material X should be minimal.
5. For conductive applications, material X should possess good electrical and thermal conductivity.

From this list of requirements, it can be seen that it would be difficult to design a barrier layer system that would meet all of the criteria so compromises typically have to be made.
For photovoltaic solar applications that require a conductive barrier layer, functional diffusion barriers can be divided into three types: polycrystalline, stuffed, and amorphous (Figure 3.3). Intuitively, epitaxial growth of a single crystal thin film would be the ultimate diffusion barrier since there would be no grain boundaries and, hence, no atomic diffusion pathways. However, the growth of such a barrier upon a metallic foil like stainless steel is not realistic because steel has a polycrystalline structure (e.g. mismatch of lattice), amongst other issues. A polycrystalline barrier layer could meet some of the barrier layer requirements by being easy to deposit, possessing good adhesive properties, and being a good electrical conductor. However, if the film was porous and not dense, it would fail the criteria of blocking kinetic traffic because of the existence of rapid diffusion pathways. Stuffed barriers, which use impurities like nitrogen to block grain boundary pathways, would reduce kinetic traffic significantly and would be a good candidate as a barrier. Another approach would be to eliminate the grain boundary pathways, altogether. This can be achieved with an amorphous barrier layer. However, amorphous barriers are meta-stable and could structurally reorganize if subjected to the
source material crystallization temperature. This reorganization would likely re-establish unwanted grain boundaries leading to problems like voids, film cracking, de-lamination, etc. and render the barrier ineffective. Also at re-crystallization temperatures, intermixing between barrier and host material could occur (Fig. 3.3; AX intermixing).

A group of materials being researched for use as barrier layers for photovoltaic devices are refractory metal nitrides like TiN and WN$_x$. Unfortunately, these metals would likely fail as barriers since they re-crystallize at temperatures too low for CIGS applications [12]. Tantalum has been widely used in the semiconductor industry as a diffusion barrier due to its high melting point, low electrical resistivity, chemical inertness, and toughness [13].
4 FILM DEPOSITION TECHNIQUES

4.1 Direct Current Magnetron Sputtering

Direct current (Dc) sputtering is a vacuum-based, physical vapor deposition technique whereby atoms are liberated from a solid target material by energetic ions and are transported towards a substrate where they condense and form a film. Figure 4.1 shows a direct current sputtering system. The circular Ta target is the source of the film that will be deposited and acts as a cathode that is negatively biased with respect to the chamber wall (which acts as an anode in the discharge). An inert working gas (e.g. argon) is introduced into the chamber and a high voltage is applied to the cathode. The electric field accelerates a few free electrons (available from background radiation or thermal energy) near the cathode towards the anode. When the electrons have sufficient energy to ionize the surrounding argon atoms during a collision, an ionization process commences with two electrons and an argon ion generated for every argon and electron collision. These interactions continue and augment until the initiation of a self-sustained glow discharge process [14]. This glow discharge, also known as plasma, consists of approximately equal amounts of ions and electrons moving randomly. Argon ions in the plasma are attracted to the negatively biased target (i.e. cathode) and become energetic. Sputtering occurs if the energy from the ions impinging the target is greater than the binding energy of the surface atoms of the target; the sputtering yield is strongly dependent on the ion energy [15].

![Schematic of a direct current (Dc) sputtering system.](image)

**Figure 4.1:** Schematic of a direct current (Dc) sputtering system.
Magnetrons are used to improve the efficiency of the sputtering process. They help increase deposition rates by making use of a magnetic field configuration to confine secondary electrons produced when the argon ions bombard the target; a benefit is that this process can occur at lower pressures so more material reaches the substrate [16]. The secondary electrons follow helical paths created by the magnetic field which restrict them close to the target surface; this increases the ionization of the argon working gas by elevating the number of collisions with neutral particles near the target surface. The argon ions are not trapped by the magnetic field because they are too heavy. This combination of Dc sputtering with a magnetron is known as direct current magnetron sputtering (DcMS).

4.2 High Power Impulse Magnetron Sputtering

4.2.1 Overview

High power impulse magnetron sputtering (HiPIMS) operates in a manner similar to that of DcMS except that the voltage applied to the sputtering cathode is pulsed instead of constant (Figure 4.2). This requires the use of a pulsed power supply which produces high peak power pulses over short periods of time to generate intense, high density plasma.

![Figure 4.2: An example of a HiPIMS voltage and current pulse [17].](image-url)
The major advantage of HiPIMS over DcMS sputtering is that the HiPIMS technique has a considerably higher degree of ionization of the sputtered material; DcMS has typically lower than 10% ionization of the sputtered species vs. over 50% for HiPIMS [18]. This is beneficial because the species arriving to the substrate surface retain some of the energy as adatoms. This results in higher adatom mobility at the surface which leads to thin film coatings which are denser (see Figure 4.3) and possess superior adhesion properties [19].

![Figure 4.3: Cross-sectional schematic of a) HiPIMS deposition and b) DcMS deposition](20)

To achieve a similar degree of ionization using DcMS would require increasing the plasma density between the target and substrate. This can be accomplished by increasing the average power to the magnetron; however, there is a limit on how much cooling can be provided to the target before it melts. This is because the thermal load of the target is limited by the average power but not by the peak power. Therefore, peak power pulses (i.e. HiPIMS) during the active discharge can be quite high without risk of the target melting.

**4.2.2 The Plasma Sheath**

The plasma sheath (also called dark zone) is the region surrounding the bulk plasma (i.e. in contact with the chamber wall and substrate) where there is a pronounced drop in voltage; because of the voltage drop there is a low concentration of electrons and,
therefore, minimal excitation of neutral species in that vicinity [21]. The HiPIMS plasma sheath has unique attributes as compared to the DcMS plasma sheath and can be exploited to deposit on surfaces with complex geometries. Figure 4.4 shows a DcMS and HiPIMS deposition into a trench. The DcMS process deposits a film on the surface and some film at the bottom of the trench but little film on the side walls of the trench due to shadowing effects. The HiPIMS process deposits at the same regions as DcMS but also more material upon the side walls and base of the trench.

![Diagram](image)

**Figure 4.4:** *a) DcMS and b) HiPIMS depositions into a trench (mm scale)* [22].

The reason for the difference in the deposition result is because the HiPIMS flux is charged and accelerated by the electric field whereas the DcMS flux is neutral and not affected by the electric field. Consider Figure 4.5 which shows a HiPIMS plasma sheath at millimeter scale and how it interacts with a complex substrate surface (e.g. stainless steel). The HiPIMS plasma sheath is thin because of the high plasma density and can conform more easily to complex geometry; the flux follows the electric field lines which are perpendicular to the substrate surface features. The end result is a larger fraction of highly ionized species arriving at the substrate surface creating denser films with improved microstructure.
Figure 4.5: A HiPIMS flux and how it interacts with the substrate (mm scale).

At sub-micron scales, the HiPIMS plasma sheath is too thick to penetrate a trench. The deposition will look similar to what is shown in Figure 4.6 where the bottom of the trench is coated but not the sides; observe that the flux arrives parallel to the substrate unlike in DcMS (i.e. less shadowing effects).

![Diagram of HiPIMS flux and sheath](image)

Figure 4.6: HiPIMS deposition into a trench (sub-micron scale) [20].

When depositing material at larger than centimeter scale, electric fields cannot be used to guide the flux because of the ability of the plasma to shield it. Instead, magnetic fields can be used to redistribute the plasma since they penetrate the plasma [22].

4.2.3 Average Power

Average power is the metric used to compare the amount of energy employed in DcMS vs. HiPIMS processes. Figure 4.7 is a schematic of HiPIMS pulses.
The average power can be calculated from the HiPIMS pulses shown in Figure 4.7 using Equation 2 below (voltage and current are the measured quantities):

$$\text{Average Power} = \frac{\int_0^T u(t)i(t)dt}{T} = \frac{\int_0^T P(t)dt}{T}, \quad (2)$$

Where: $u =$ voltage, $i =$ current, $T =$ period, and Peak Power = $P = u \cdot i$

There are three ways to change the average power in HiPIMS:

1) adjust pulse voltage  
2) change frequency  
3) vary duty cycle

The duty cycle is the fraction of the “on-time” of the pulse, see Equation 3:

$$\delta = \frac{t_{\text{pulse}}}{T}, \quad (3)$$

Where: $\delta =$ duty cycle, $t_{\text{pulse}} =$ pulse width (s), and $T =$ period (s)

**4.2.4 Deposition Rate**

A drawback to the HiPIMS technique is the lower deposition rate achieved as compared to DcMS when the same average power is used; however, recent (unpublished) research results indicate that the HiPIMS deposition rate can be enhanced considerably by optimizing (i.e. reducing) the magnetic field generated by the magnetron.
The lower HiPIMS deposition rate is partially due to some energy going towards increasing the ionization of the plasma (which is beneficial) and some energy going towards self-sputtering (which is undesirable). Self-sputtering is a phenomena that can occur and become more prevalent in HiPIMS as a function of increasing plasma ionization. When a metal atom is sputtered and ejected from the target, it can be ionized close to the target by the dense plasma and attracted back up towards the target and re-sputter the target (and become a neutral metal atom that sticks to the target). An ion is lost in the process which reduces the sputter yield as compared to using argon as the sputter specie.

A HiPIMS strategy that can be implemented to increase the deposition rate to be more competitive with DcMS is to increase the average power of the HiPIMS process relative to DcMS. For example, if the pulse width (i.e. \( t_{\text{pulse}} \)) and pulse frequency are kept constant and the peak power to the cathode is increased (from 100kW to 200kW as illustrated in Figure 4.7), then the average power increases and, hence, the deposition rate. This strategy can be considered fallacious since the average power required to run HiPIMS at the higher deposition rate is greater than what is needed to achieve a similar deposition rate using DcMS. Also, a major shortcoming is that using a higher peak power in the HiPIMS process can lead to arcing.

### 4.2.5 Arcing

The phenomena of arcing is thought to be caused by a rapid accumulation of electron charge at a small region of dielectric (i.e. insulating contaminant) on the target surface which violently discharges towards a region with low impedance conditions [23]. The tendency for arcing to occur is partially related to the choice of target material and target purity. Materials with a high melting point like tantalum have a lower frequency of arcing vs. materials with a low melting point (e.g. aluminum). Arcing can generate particulates on the substrate surface which can cause defects and poor adhesion properties. Contamination in the deposition chamber will also increase the probability of arcing.
In a HiPIMS deposition, there are multiple ways an arc can form. For example, the propensity for arcing to occur on the surface of the cathode increases as the amount of energy (i.e. joules/pulse) to the cathode is increased. In order to reduce the tendency of arcing and stabilize the HiPIMS deposition process, it is typical for the frequency to be increased and/or the pulse width shortened. Consequently, these adjustments affect the average power and, therefore, the deposition rate and ionization.
5 EXPERIMENTAL DETAILS

5.1 Overview

This chapter describes how silicon (Si) wafer and stainless steel (SS) foil substrates were prepared for deposition. Ideally, SS pieces would be used to determine film deposition rates and to study cross-sectional film morphology. However, since there was no practical way to cut a coated SS foil without smearing the interface between film and foil, silicon pieces were used instead.

5.2 Si Substrate Preparation

The Si wafers were cut into 1cm x 1cm pieces. The pieces were cleaned prior to deposition using the following procedure. First, the Si was placed in a beaker filled with acetone and run in an ultrasonic cleaner for 5 minutes. Next, the Si was transferred to a beaker filled with 2-isopropanol and run in an ultrasonic cleaner for another 5 minutes. Finally, the Si was removed from the beaker and dried with pure nitrogen gas.

5.3 Vacuum Chamber System

The depositions were performed in a high vacuum system. The cylindrical vacuum chamber had a height of 0.7 meters and a diameter of 0.44 meters. The chamber was equipped with a circular tantalum target that had a diameter of 6 inches; the target was water cooled to prevent it from melting. The magnetron that was used was unbalanced. The power supply used was a Chemfilt SINEX 3.0 device that could operate in either Dc or HiPIMS mode. The turbo-molecular pump attached to the chamber could achieve a background pressure as low as ~10⁻⁷ torr. Argon with N60 purity was used as the working gas; nitrogen with N60 purity was used as the reactive gas for select depositions. Both gases were introduced into the chamber using a mass flow controller.

5.4 Si Preparation for Cross-Sectional Characterization

Si pieces were prepared for scanning electron microscopy characterization using the following procedure. First, the square Si piece was scored down the middle. Next, it was dipped into a bath of liquid nitrogen (LN₂) for ~2 minutes. Finally, the Si piece was removed from the bath and cracked along the score line.
6 RESULTS

6.1 Overview
In this chapter, coated Si and SS samples were characterized using scanning electron microscopy (section 6.2) to study film morphology and determine film deposition rates.

6.2 Scanning Electron Microscopy (SEM) of Si samples
Cross-sectional scanning electron micrographs of silicon pieces are shown in Figures 6.1, 6.2, 6.3, and 6.4. The magnification levels of the SEM micrographs were the same except for Figure 6.2. Figure 6.1 is from a DcMS deposition. From the image it can be seen that there is columnar growth with voids between some of the columns.

Figure 6.1: Cross-sectional scanning electron micrograph of a DcMS Ta film deposited on Si.

The flake features seen at the bottom half of the film are a result of an untrue cracking of the Si piece during SEM preparation. Figure 6.2 is from a HiPIMS deposition. The image reveals a denser columnar microstructure as compared to the DcMS film from Figure 6.1.
Figure 6.2: Cross-sectional scanning electron micrograph of Ta deposited onto Si using HiPIMS. The shadow visible in the upper left quadrant of the image is due to burn-in artifacts from the SEM electron gun.

Figure 6.3: Cross-sectional scanning electron micrograph of TaN deposited onto Si using reactive HiPIMS.
Figure 6.3 is from a reactive HiPIMS deposition. The morphology of the film in Figure 6.3 is dense but with slightly wider columns than that shown in Figure 6.2. Figure 6.4 is from a HiPIMS deposition with different parameters than those used to deposit the film seen in Figure 6.2. The film has no discernable features.

![Cross-sectional scanning electron micrograph of Ta deposited onto Si using HiPIMS.](image)

**Figure 6.4:** Cross-sectional scanning electron micrograph of Ta deposited onto Si using HiPIMS.

### 6.3 Scanning Electron Microscopy (SEM) of SS samples

The surface morphology of two SS substrates was also studied using SEM. Figure 6.5 is of an uncoated SS substrate. The substrate was not polished. This is evident from the image which reveals a rough, non-uniform surface with scratches, protrusions, and pits; two large crevices span the upper right half of the image. Figure 6.6 is of a HiPIMS Ta coated SS substrate. The surface is decorated by a network of dense, regularly spaced grain facets. No scratches, protrusion, or pits are visible on the surface as compared to the uncoated SS from Figure 6.5; an outline of a crevice feature can be seen on the left side of the image.
**Figure 6.5:** Plan-view of an uncoated SS substrate.

**Figure 6.6:** Plan-view of a Ta coated SS substrate from sample G. The inconsistent contrast of the image at multiple regions on the surface may be due to burn-in artifacts from the SEM electron gun.
7 CONCLUSION

- Cross-sectional scanning electron micrographs revealed that the HiPIMS coatings appeared denser than the DcMS coatings.
8 FUTURE RESEARCH

- Perform secondary ion mass spectrometry (SIMS) and sputtered neutral mass spectrometry (SNMS) depth profiling on barrier coatings to determine concentrations of impurities in the barrier film. This will help to optimize barrier layer thickness as a function of impurity diffusion.

- Utilize a deposition system that sputters upward or horizontally so that no particulates (i.e. contamination) fall on the SS substrate which could cause shadowing on the surface.
REFERENCES


