VN thin films grown by high power impulse magnetron sputtering

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Abstract

Thin vanadium nitride films were grown on SiO_2 by reactive high power impulse magnetron sputtering (HiPIMS). We explored the influence of the nitrogen partial pressure, stationary magnetic confinement field strength, operating pressure, and substrate bias, on the film properties. Structural characterization was carried out using X-ray diffraction and reflection methods as well as pole scan measurement. Our results show that an Ar/N_2 mixture with 8/1 ratio is sufficient to grow cubic δ-VN. HiPIMS grown films are denser and have lower surface roughness when grown at low pressure < 1 Pa. The films grown by HiPIMS with strong magnetic confinement exhibit higher density and lower roughness. Lowering the magnetic field strength increases the deposition rate significantly for reactive HiPIMS. VN film grown at substrate bias of -50 V exhibits the highest density and deposition rate, lowest surface roughness and lowest electrical resistivity. From GiXRD it can be concluded that biased substrate leads to highly (200) textured VN film. Pole scans show that by increasing bias voltage, the angle between the (200) plane and the substrate plane become smaller and for substrate bias of -200 V they become almost parallel.

Introduction

In high power impulse magnetron sputtering (HiPIMS), high power is applied to the magnetron target in unipolar pulses at low duty cycle and low repetition frequency while keeping the average power about two orders of magnitude lower than the peak power [1]. This results in a high plasma density, and high ionization fraction of the sputtered material.

Reactive sputtering, where metal targets are sputtered in a reactive gas atmosphere to deposit compound materials, including transparent conductive oxides, permeation barrier coatings, hard coatings, etc., is of utmost importance in various technologies.

In reactive sputtering processes a reactive gas (e.g., O_2, N_2, CH_4, etc.) is mixed to the noble working gas to synthesize a compound film.

Polycrystalline VN thin films are used in a number of applications including diffusion barriers in micro electronic devices [2], as hard wear and scratch-resistant coatings [3], and as a potential electrode material for energy storing systems (super capacitors) [4].

Here we explore the growth of VN films by HiPIMS while varying the nitrogen flow rate, the operating pressure, magnetic field strength [5] and substrate bias voltage.

Experimental findings

Nitrogen addition

To grow VN film, Ar/N_2 gas mixture was injected into the chamber.

Figure 1 shows GiXRD pattern for films which were grown by HiPIMS at 0, 2, 3, 4 and 5 sccm nitrogen flow rates. Ar flow rate was kept at 40 sccm in all cases. Comparing the obtained GiXRD peaks with reference peaks indicates that 5 sccm nitrogen flow rate is sufficient to grow good polycrystalline VN films.

Pressure and magnetic field strength

Figure 2 shows the film density versus the operating pressure for HiPIMS grown film with both strong and weak magnets.

We see that the film density decreases with increased operating pressure while surface roughness increases with increased discharge pressure.

Using stronger magnet leads to denser and smoother films at all pressures. However, stronger magnetic field decreases the deposition rate.

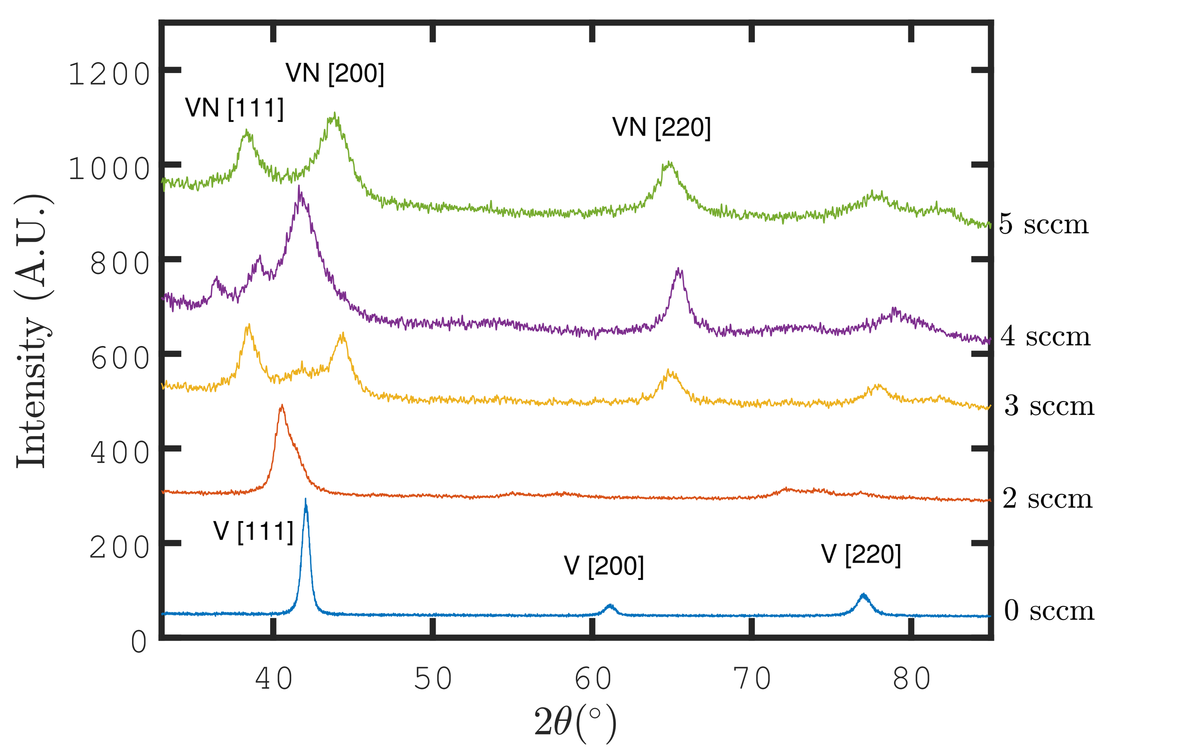

Figure 1: GiXRD pattern from VN films which were grown by HiPIMS at different nitrogen flow rates.

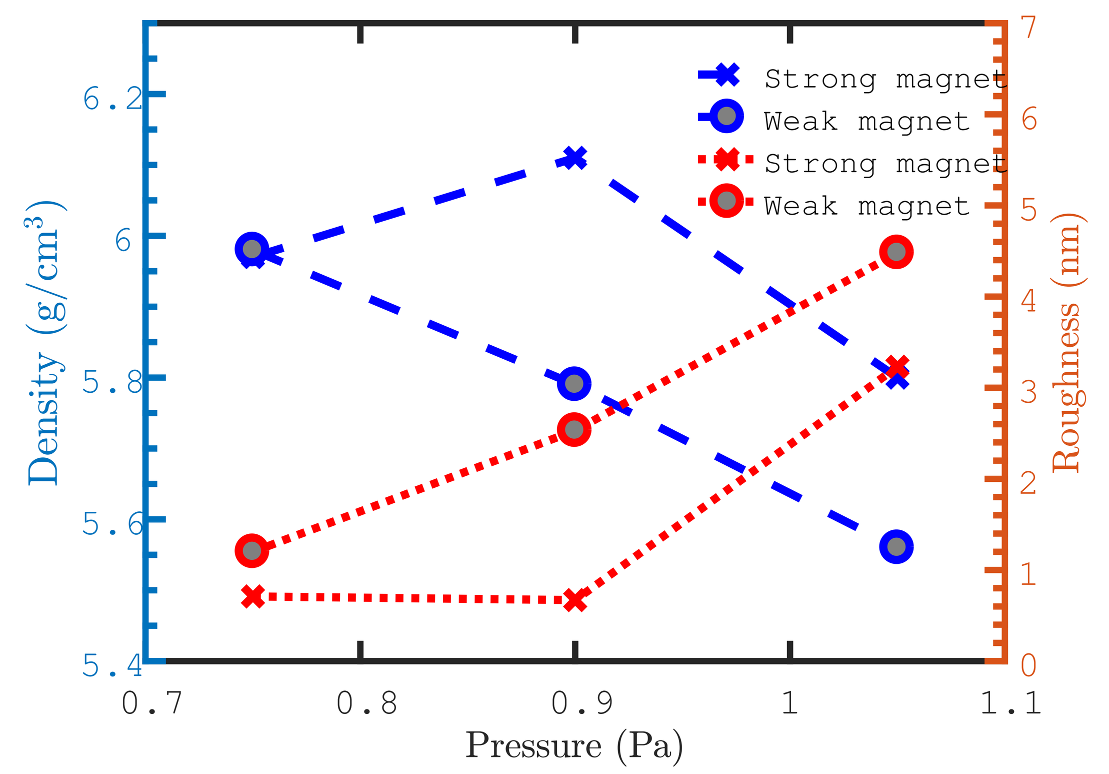

Figure 2: Film density and roughness of VN films grown by HiPIMS for strong and weak magnets at different pressures.

Substrate bias voltage

For grounded substrate deposited films the (111) and (200) peaks show similar intensities. Increasing the bias voltage further up to -200 V leads to a gradual decreases in the (200) intensity while that still remains the dominant peak.

The film grown with -50 V bias has mass density of 6.03 g/cm^3 which is significantly denser than the one grown with grounded substrate (5.60 g/cm^3). Increasing the substrate bias voltage to -100 V leads to density decrements to 5.93 g/cm^3.

As can be seen in Figure 4(b) deposition rate at -50 V is 1.09 nm/min which is slightly higher than for the film grown at 0 V. At higher bias voltages the deposition rates gradually decrease.

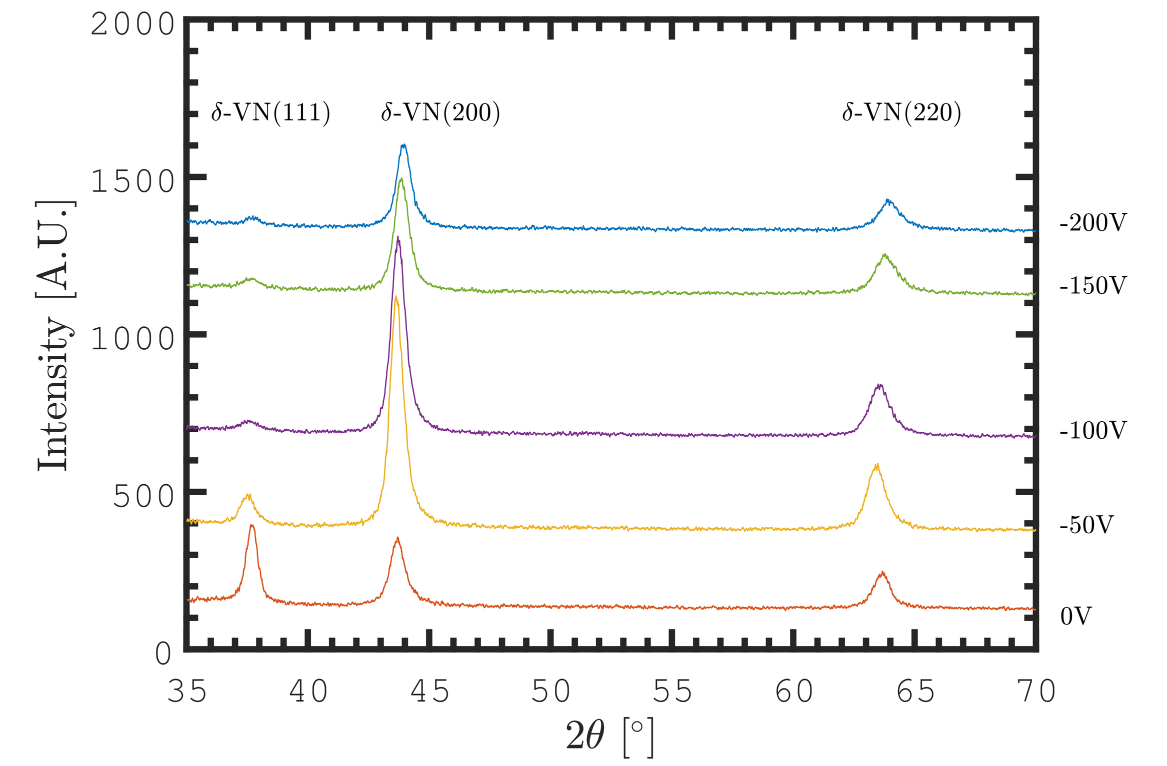

Figure 3: GiXRD pattern from vanadium nitride films which were grown by HiPIMS at different substrate bias voltage.

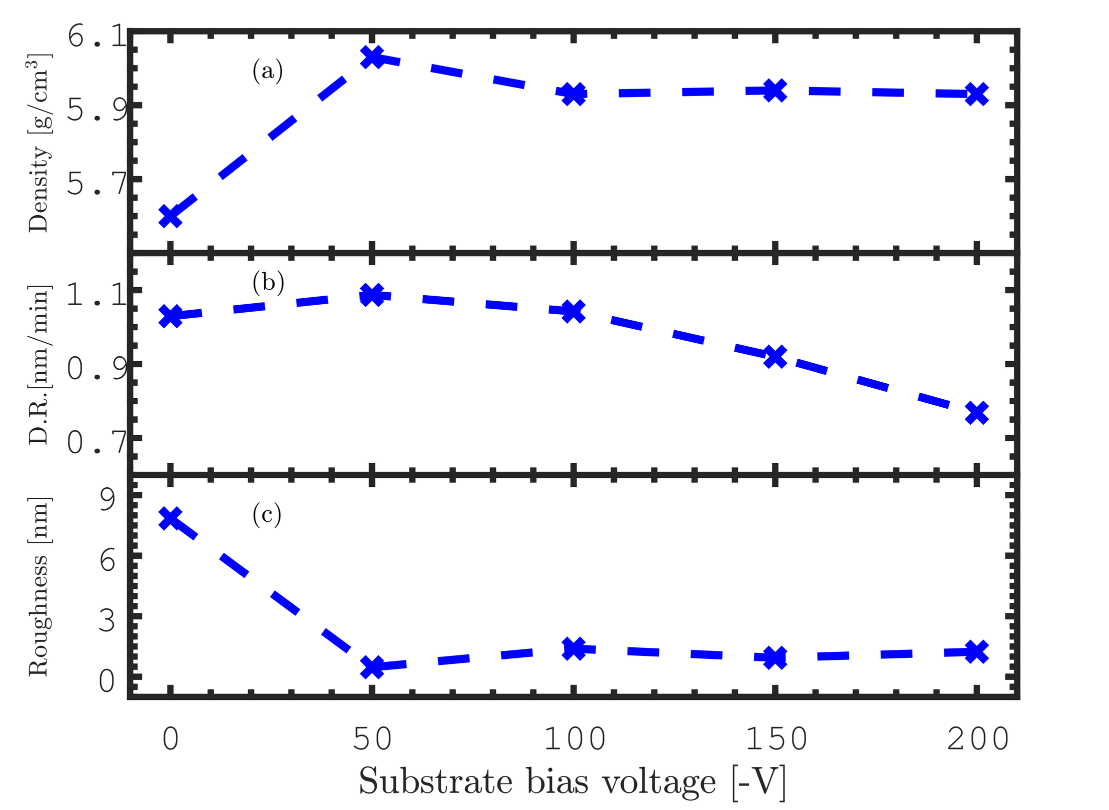

Figure 4: (a) Film density, (b) deposition rate, and (c) surface roughness of vanadium nitride films grown as a function of substrate bias voltage.

Figure 4(c) depicts how applying the bias voltage to the substrate results in remarkably smoother VN film surface.

The pole figures of the (111) and (200) planes for VN grown films at different substrate biases are displayed in Figure 5. It can be seen that the film grown at grounded substrate has uniformly distributed orientation of (200) planes while the (111) planes show an intense spot around $\psi = 0$ indicating considerable $\langle 111 \rangle$ texture normal to substrate.

Increase of bias to -100 V causes the $\langle 111 \rangle$ texture to disappear but the (200) planes shows up at $\psi = 15°$ with respect to substrate normal. Further increase in the substrate bias results in dominant $\langle 200 \rangle$ normal to the substrate.

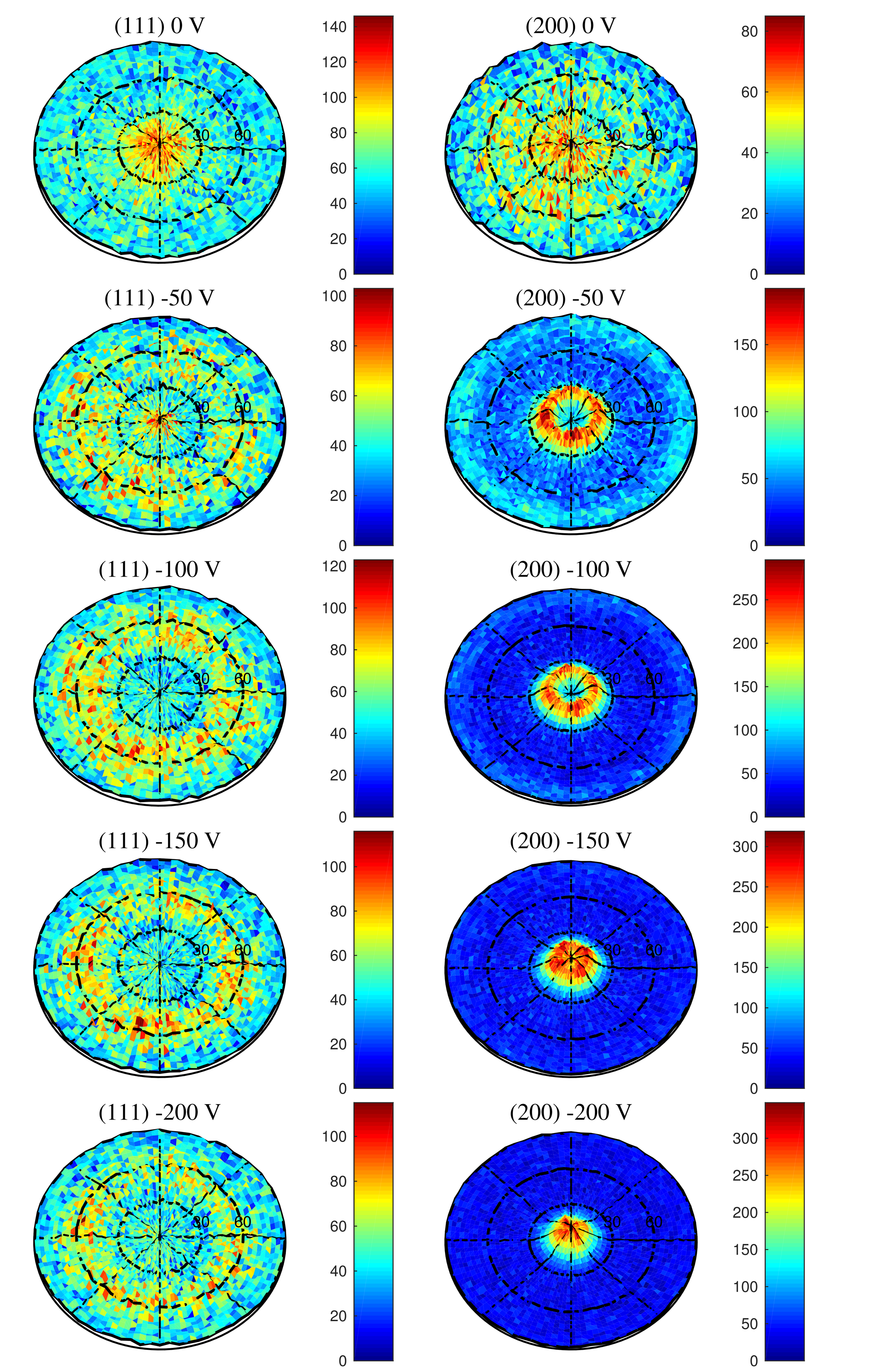

Figure 5: Pole figures of the (111) and (200) planes for vanadium nitride films which were grown by HiPIMS under different substrate bias voltage.

Conclusions

- A mixture of 40 sccm Ar and 5 sccm N_2 (ratio of 8/1) is sufficient to grow stoichiometric cubic δ-VN film by HiPIMS.
- Deposition of VN films at low pressure and high magnetic field confinement results in denser and smoother film.
- Applying bias voltage to the substrate leads to remarkably denser and smoother VN films. It was found that -50 V is optimum substrate bias voltage in this regard.
- By increasing the substrate bias voltage, film texture changes from off-normal $\langle 200 \rangle$ texture to $\langle 200 \rangle$ texture normal to the substrate.

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