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High Deposition Rate Symmetric Magnet Pack for High Power Pulsed Magnetron Sputtering

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ABSTRACT

High power pulsed magnetron sputtering is a promising physical vapor deposition technique with two minor challenges that obstruct its broader implementation in industry and its use by researchers. The first challenge is the availability of low cost HPPMS power supplies with output power under 2 kW. Such power supplies are suited for circular planar magnetrons with target diameters between 50 mm to 150 mm. The second challenge is the overall lower deposition rates of HPPMS when compared with direct current magnetron discharges. The "ε" magnet pack designed for a 100 mm sputter magnetron which was developed by the Center for Plasma Material Interactions at the University of Illinois at Urbana Champaign in collaboration with Kurt J. Lesker Company was capable of producing twice higher deposition rates in HPPMS compared to a conventional magnet pack. The cylindrically symmetric "TriPack" magnet pack presented here was developed based on magnetic field design solutions from the "ε" magnet pack in order to keep the high deposition rates, but improve deposition uniformity, without the need for substrate rotation. The new cylindrically symmetric magnet pack for 100 mm diameter targets, along with a specially designed cooling well provides stable operation at 2 kW average power, even with low-temperature melting-point target materials. The deposition rates from the TriPack magnet pack is compared with a commercial conventional magnet pack for DC and HPPMS power supplies.

1. Introduction

High power pulsed magnetron sputtering (HPPMS), or high power impulse magnetron sputtering (HiPIMS), is a type of magnetron sputtering technique where high power pulses, with durations of hundreds of microseconds are applied to the magnetron target at frequencies ranging from a few Hz to several kHz. In such a discharge, the peak power densities during the pulse can be on the order of several tens of kilowatts per square inch whereas the average power densities are comparable to or equal to direct current magnetron sputtering (dcMS) discharges [1] to avoid melting or overheating the sputtering target. These high peak power pulses result in electron densities of 10^{19} m^{-3}, which are three orders of magnitude higher than dcMS discharges [2]. Such high electron densities lead to ionization of the sputtered material, which in turn leads to a higher density of ion flux towards the substrate [3]. The higher ionization fraction of sputtered material, and the lower thermal load on to the substrate lead to high quality thin films [4,5]. Until recently, it was believed that HPPMS/HiPIMS was a technique with low deposition rates that could only be used in a limited number of applications [6]. To understand the reasons behind such low deposition rates in HiPIMS, extensive studies were performed by many research teams around the globe [7]. The importance of the following aspects of a magnetron were shown: magnetic field magnitude and the magnetic field profile on the magnetron target surface [8–10], plasma impedance [11], plasma instabilities [12] and power supply pulsing parameters [13,14].

The wide range of mentioned experimental work was not enough to develop a mathematical model that could describe the quantitative contributions from each of the above mentioned factors to deposition rates in HiPIMS. A quick conclusion from all the previous experimental work is that, the shape and magnitude of the magnetic field above the cathode has the major contribution to the deposition rates. The Center for Plasma Material Interactions (CPMI) started out with a series of experiments [15] to search for an optimal magnetic field configuration for pulsed magnetron discharges. The experimental results for a 4″ diameter magnetron sputter gun are discussed in this article.

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2. Experimental set-up

Sputtering high-purity atomic deposition experiment (SHADE) is a dual magnetron setup for depositing thin films in an ultra-high vacuum (UHV) environment. The SHADE chamber (Fig. 1(a)) has a load lock for sample transfer and a rotatable substrate holder for increasing the film uniformity during deposition. Huettinger TruPlasma Highpulse 4002 DC Generator power supply (average power: 0–10 kW; maximum voltage: 2000 V; maximum current: 1000 A; pulse length 1–200 μs; frequency: 1–400 Hz) and Starfire impulse power supply (average power: 0–2 kW; maximum voltage: 1000 V; maximum current: 200 A; pulse length 5 μs–1 ms; frequency: 1 Hz–10 kHz) were used for HiPIMS discharges. The Advanced Energy pinnacle plus power supply (average power: 0–10 kW; voltage: 325–650 V; maximum current: 30 A) was used for dcMS discharges. Aluminium, titanium, copper and carbon targets were tested in this work. The deposition rates were measured using a dual water-cooled Quartz Crystal Microbalance (QCM) that was placed 4″ from the target surface, on the axis of the magnetron gun. The QCM assembly was attached to a rotatable feed through. During the experiments, the QCM assembly was moved from the center of one magnetron to the other so the deposition rate comparison experiments could be done without breaking the vacuum. The base pressures on the SHADE chamber were ~1×10^{-7} Torr and the gas flow to the chamber was regulated by mass flow controllers (MFC). Kurt J. Lesker Company's standard 4″ Torus magnetron sputter gun was used for this work. The commercial Torus comes with a conventional arch shaped magnetic field configuration (Fig. 2(a), (d) and (g)), where the arch of the magnetic field lines starts from the center of the magnetron target and continues to the outer edge. This type of magnet pack will be referred to as a “conventional magnet pack”. For the TriPack that is described in this article, a specially designed magnetron and target were used. The target was 0.25″ thick and was machined to accommodate four concentric rings made out of magnetic material (soft iron). These rings served as magnetic field conduits that helped in obtaining the same magnetic field values above the target as in the conventional pack. Since these rings were only 0.125″ tall and were embedded in to the back of the target surface that is attached to the cooling well side, no iron was exposed to plasma. Also, the target was machined to look like a pre-eroded target to obtain the required magnetic field magnitudes on the target surface. Fig. 1(b) is a 2D axisymmetric illustration of the modified TriPack target, where the gray colored rectangles represent the iron pieces. The colored iso-lines show the total magnitude of the magnetic field in Gauss. This should not be misinterpreted with the surface magnetic field plots shown in Fig. 2(a)–(c) where only the radial component of magnetic field is presented.

3. Magnet field design and simulations

COMSOL Multiphysics finite element analysis software was used to simulate the magnetic field profile above the target surface in this work. The magnetic and electric field modules of COMSOL Multiphysics was used to calculate the magnetic flux densities and surface magnetic

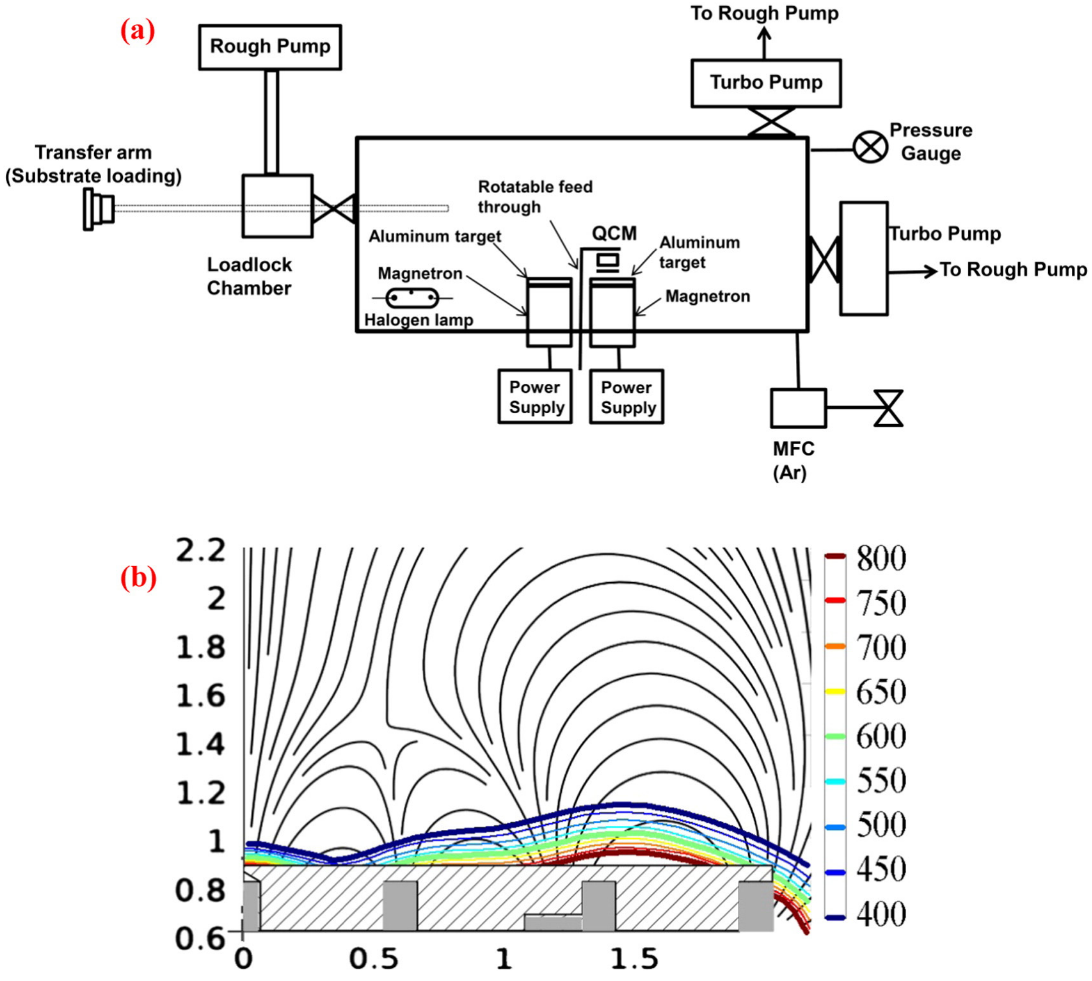

Fig. 1. (a) Schematic diagram of the SHADE chamber, (b) 2D axisymmetric illustration of the modified TriPack target. The colored iso-lines show the total magnitude of magnetic field in Gauss.