Hiden Reference: AP0193
Hiden Product: PSM Plasma Ion Analyser

Overcoming the geometrical limitations of conventional sputtering by controlling the ion-to-neutral ratio during high power pulsed magnetron sputtering

Thin films prepared by magnetron sputtering on substrates not facing the sputtering target often exhibit pronounced column tilt in the direction of incoming flux (see Fig.1(a)). The column tilt angle γ (relative to the surface normal) is smaller than the angle defined by the direction of incoming flux (δ). For $0° \leq \delta \leq 60°$ the so-called tangent rule applies and both angles are related by $2\tan\gamma = \tan\delta$. The effect of column tilt, commonly observed for films grown on obliquely-mounted substrates by direct current magnetron sputtering (DCMS), is believed to result from the conservation of the momentum component parallel to the film surface. Surface diffusion also plays a role such that columns tend to tilt back towards the vapor incident direction. As clearly demonstrated in Fig.1(a) resulting films exhibit open microstructure with numerous voids between the columns. In addition, surface roughness is high. All of these are serious drawbacks if the deposited film should serve as the protective coating on 3D multi-shaped objects. In such case all surfaces that are not facing the target during deposition, (*e.g.*, the rake face of the cutting tool) will exhibit the microstructure as the one shown in Fig.1(a).

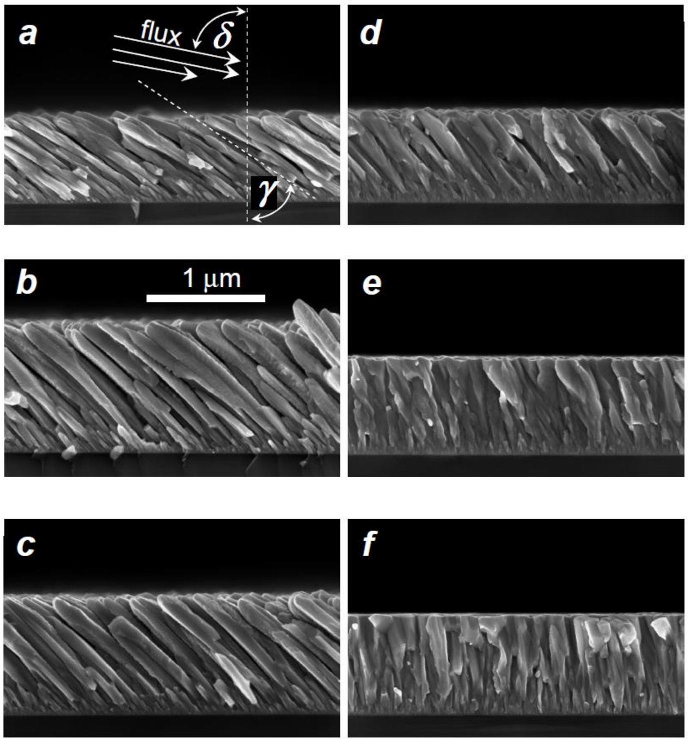

Figure 1

The line-of-sight nature of the conventional DCMS processing manifested by, e.g., pronounced column tilt on obliquely-mounted substrates, could be potentially avoided if film-forming species were to arrive at the growing film surface along the surface normal (as it is the case for films facing the target during deposition). This cannot be easily achieved with DCMS, as the material flux sputtered from the target is dominated by neutrals that are not affected by the application of electric or magnetic fields. However, during the high-power pulsed magnetron sputtering (HIPIMS or HPPMS), where the power is applied to the target in short (~100 μs) high-amplitude (several kW/cm^2) pulses, the metal ion content in the plasma can be very high.

Therefore we use HIPIMS to grow thin chromium layers on substrates facing and orthogonal to the sputtering target. We apply the negative substrate bias with the amplitude of 150 V to effectively steer the ions along the surface normal by increasing the momentum component perpendicular to the film surface. By using a PSM003 Mass Spectrometer from Hiden Analytical, UK to monitor ion fluxes during the high-power pulses we are able to show that upon increasing the peak target current density, j_T from 0.1 to 1.7 A/cm^2 the Cr ion-to-neutral ratio in the flux to the substrate increases several times. This has dramatic consequences for the microstructure of the thin Cr layers grown on the substrates orthogonal to the target, as illustrated by the scanning electron microscopy images shown in Fig.1(b)-(f). The large column tilt characteristic for the growth at low j_T (DCMS-like conditions) decreases with increasing the relative metal ion content in the flux and almost completely disappears at the highest value of j_T (see Fig.1(f)) The latter indicates that the material flux to the substrate is highly ionized so that all film-forming species arrive close the substrate normal, despite the high nominal inclination angle (δ is fixed for all experiments). Thus, in the limit of high j_T the artifacts of conventional DCMS, resulting from the line-of-sight deposition, are effectively eliminated and the film growth proceeds more or less unaffected by the substrate orientation. In consequence, samples mounted orthogonally possess a similar texture, morphology, and topography as those facing the target.

Project Summary by:

G. Greczynski, J. Jensen and L. Hultman
Department of Physics (IFM)
Thin Film Physics Division
Linköping University,
581 83 Linköping,
Sweden

Paper Reference:
G. Greczynski, J. Jensen and L. Hultman (2011) “Mitigating the geometrical limitations of conventional sputtering by controlling the ion-to-neutral ratio during high power pulsed magnetron sputtering” *Thin Solid Films* **519** (19), 6354-6361.

Hiden Product:
PSM Plasma Ion Analyser

Follow the link to the product catalogue on our website for further information
http://www.hidenanalytical.com/index.php/en/product-catalog/51-plasma-characterisation/81-hiden-psm-mass-and-energy-analyser-for-plasma-diagnostics