# Growth of $TiO_2$ thin films by high power impulse magnetron sputtering

F. Magnus,[1,*] B. Agnarsson,[1] A. S. Ingason,[1,2] K. Leosson,[1] S. Olafsson[1] and J. T. Gudmundsson[1,3]

1. Science Institute, University of Iceland, 107 Reykjavik, Iceland
2. Thin Film Physics Division, IFM-Materials Physics, Linkoping University, Linkoping, Sweden
3. UM-SJTU Joint Institute, Shanghai Jiao Tong University, Shanghai, 200240, China

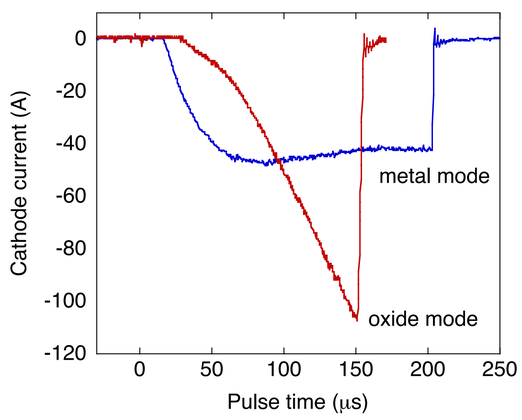
*e-mail: fridrikm@hi.is

## Introduction

- High power impulse magnetron sputtering (HiPIMS) is an emerging ionized physical vapour deposition technique [1]
- By pulsing the sputtering target with high power (~1kW/cm$^2$), short duration (~100 µs) pulses, a high ionization of the sputtered species is obtained, without significant target heating
- HiPIMS has been shown to have several advantages over conventional dc magnetron sputtering (dcMS) including increased film density, lower roughness, increased reactivity at low temperatures and better step coverage [2]
- The aim of this study is to compare thin $TiO_2$ films grown by HiPIMS and dcMS at various substrate temperatures
- $TiO_2$ finds application in a variety of electrical and optical devices due to its high refractive index and good thermal stability
- Structural properties are examined by grazing incidence X-ray diffraction (GIXRD) and X-ray reflection (XRR) measurements
- Optical properties are determined by ellipsometry

## Deposition and discharge characteristics

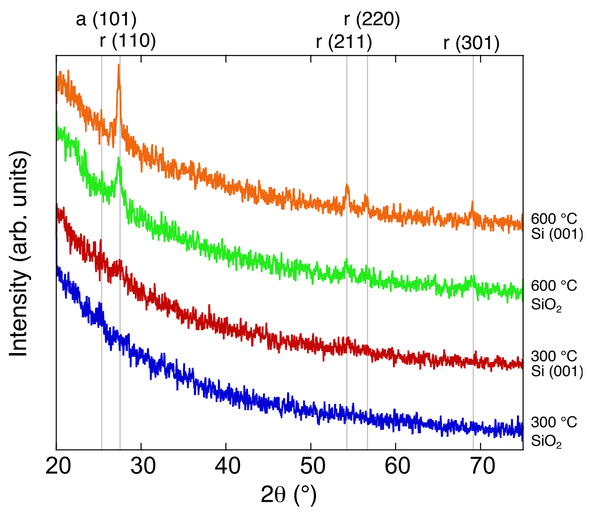
- HiPIMS
  - Square 530 V pulses
  - Pulse length 200 µs, repetition frequency 75 Hz,
  - Peak power density 0.7 kW/cm$^2$, average power 350 W
  - Ar/$O_2$(3.2%) gas mixture, total pressure 0.7 Pa
  - A distinct change in pulse shape is seen with the transition from metal to oxide mode → plasma ignition is delayed but the peak current increases in oxide mode
  - All films were grown in metal mode with a growth rate of 0.3 Å/s resulting in a film thickness of 50–60 nm (measured by XRR and ellipsometry)
  - Grown simultaneously on Si(001) and amorphous $SiO_2$ (500 nm thermally oxidized Si)
- dcMS
  - Power 140 W
  - Ar/$O_2$(5.4%) gas mixture, total pressure 0.5 Pa
  - metal mode growth, growth rate of 0.6 Å/s resulting in film thicknesses of 100–120 nm (measured by XRR)
- 3 inch Ti target of 99.995% purity



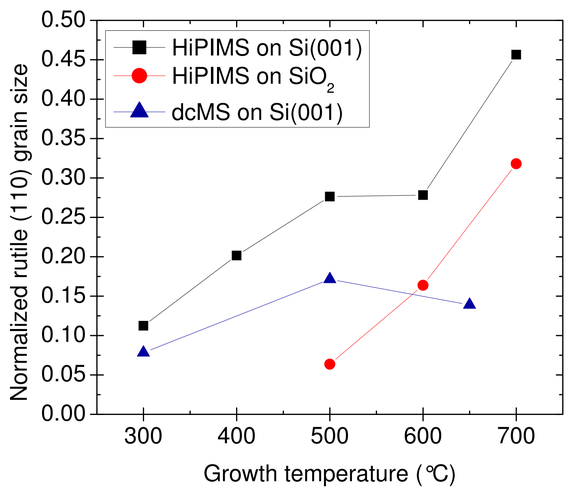

Pulse waveforms during metal and oxide mode. The voltage pulse is square and starts at t = 0. The pulse is cut short in oxide mode to limit the current

## Phase composition

- GIXRD scans show that all the films are polycrystalline
- HiPIMS gives significantly larger grains than dcMS
- Growth on Si substrates promotes the nucleation of rutile grains and results in a larger grain size than when $SiO_2$ substrates are used
- Where diffraction peaks are visible they correspond to the rutile phase, except for the film grown on $SiO_2$ at 300 °C by HiPIMS where a small anatase peak is observed



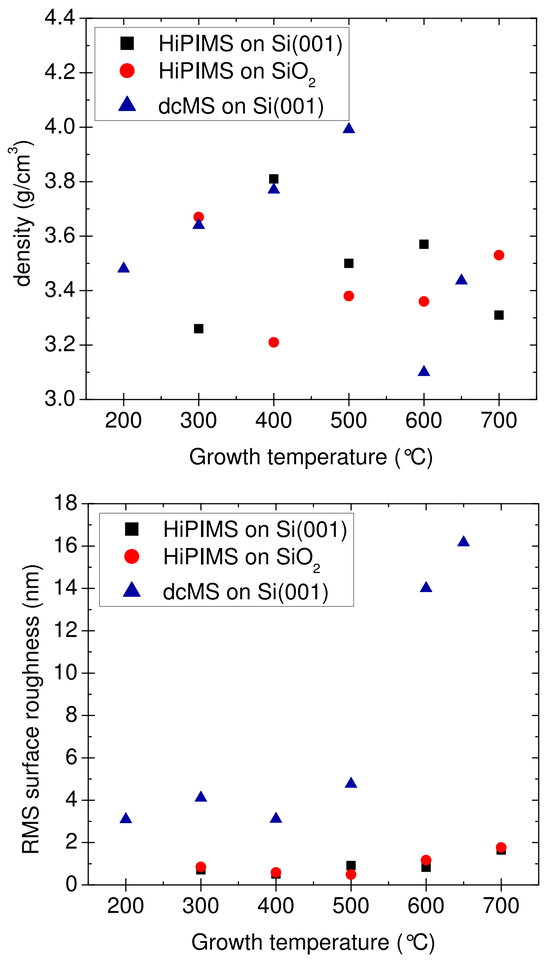

Grazing incidence x-ray diffraction measurements of HiPIMS-grown TiO2 films

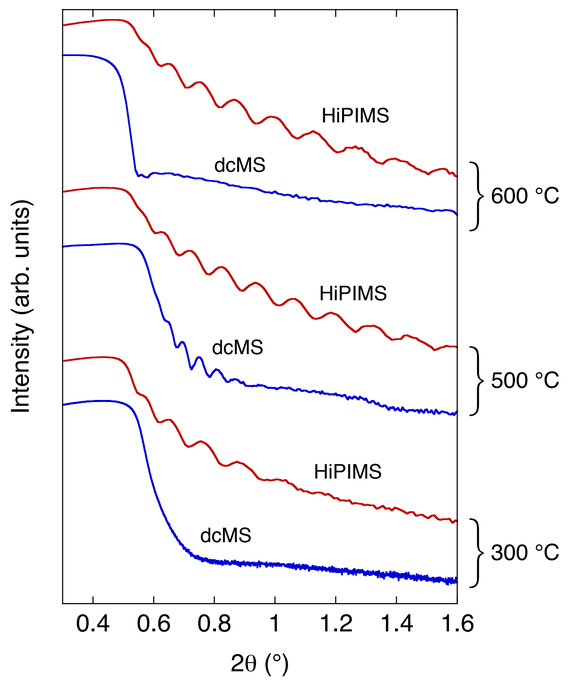



Rutile (110) grain size calculated from the FWHM of the (110) peak, normalized by film thickness

## Roughness and density

- XRR shows that films grown by HiPIMS have an order of magnitude lower surface roughness than films grown by dcMS
- Roughness increases with growth temperature
- Surface roughness is similar for Si and $SiO_2$ substrates
- Film density is lower than expected for rutile or anatase phases, despite large grain size → indicates porosity
- No obvious trends observed in film density with growth temperature

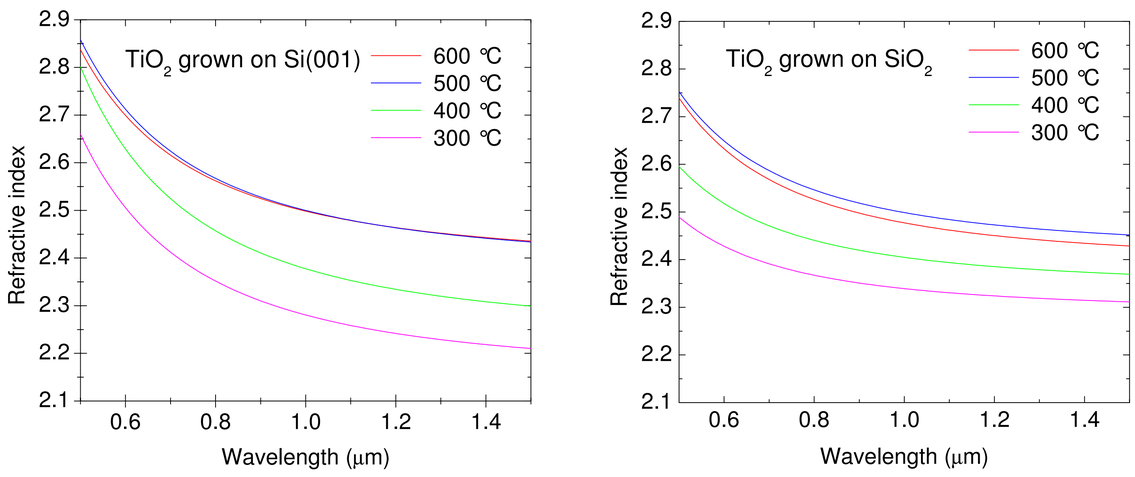



X-ray reflection curves of HiPIMS and dcMS-grown films, including the surface roughness and density extracted from fitting

## Refractive index

- Refractive index and film thickness measured by ellipsometry
- Refractive index of HiPIMS-grown films is well described by a simple Cauchy relation ($A+B/\lambda^2$) in the wavelength range 500–1500 nm
- Refractive index for dcMS grown films cannot be described by a Cauchy relation
- Refractive index varies with deposition temperature, is highest at 500–600 °C
- At 800 nm the refractive index is 2.56 for films grown at 500 and 600 °C




## Conclusions

- HiPIMS produces rutile $TiO_2$ films with larger grains than dcMS in the temperature range studied (300–600 °C)
- The surface roughness is dramatically reduced in HiPIMS-grown films compared to dcMS
- HiPIMS produces optically transparent films with a high refractive index whereas dcMS-grown films show an anomalous variation in refractive index with wavelength

## References

1. U. Helmersson, M. Lattemann, J. Bohlmark, A. P. Ehiasarian, J. T. Gudmundsson, Thin Solid Films **513**, 1 (2006)
2. K. Sarakinos, J. Alami, S. Konstantinidis, Surface & Coatings Technology **204**, 1661 (2010).

This work is partially funded by the Icelandic Research Fund, the University of Iceland Research Fund and the Steinmaur foundation