PROPERTIES OF E-BEAM EVAPORATED TITANIUM OXIDE THIN FILM

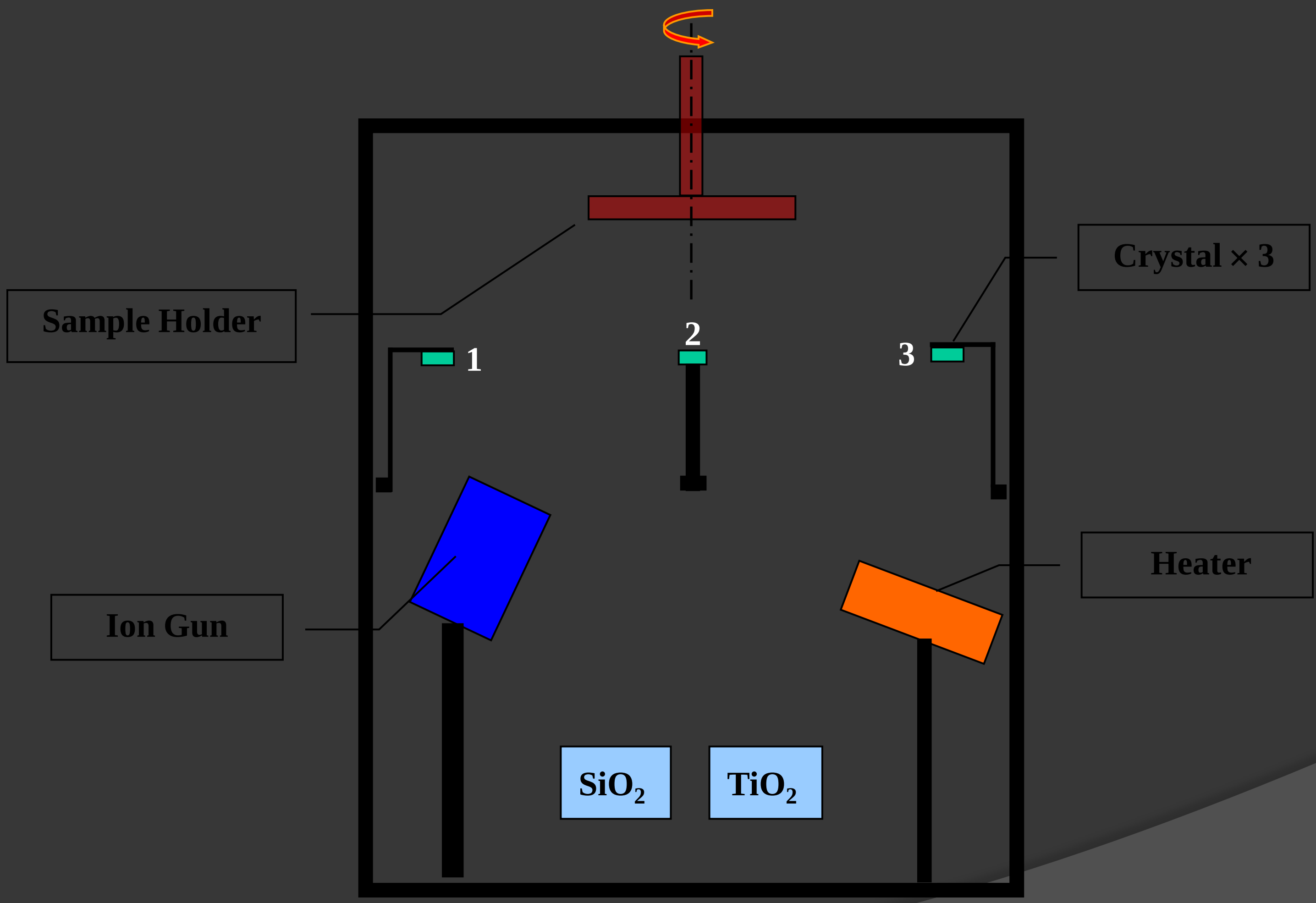
Ping Hou
Nortel Networks Co.
Richard Sun
Angstrom Sun Technologies Inc.

Presented at MRS Fall Meeting 2002 in Boston

Introduction

Titanium oxide (TiO_2) thin film has been widely used as optical coatings due to its high index of refraction. It is well known that structures and properties of TiO_2 films are highly dependent on the processing techniques. E-beam evaporation has long been recognized as a practical way of depositing optical thin films. However, preparing a homogenous TiO_2 film with this technique is still a challenge. One of the difficulties of getting a structurally uniform TiO_2 film lies in the fact of its low phase transformation temperature. It is vital to find a fast and non-destructive way to monitor and evaluate the film optical quality. It is also important to tail the film stress at will to satisfy mechanical requirements for MEMs devices, such as vertical cavity surface emission laser (VCSEL). To this end, the stress and structural homogeneity of e-beam evaporated TiO_2 films will be examined and discussed in this research.

Deposition Chamber



Deposition Process

Table 1. Experiment Conditions for Structural Study

Deposition Rate (Å/s)	2.0
Chamber Pressure (Torr)	2.5×10^{-4}
Anode Voltage (V)	130
Anode Current (A)	1.0

Table 2 Experimental Conditions for Stress Study

Deposition Rate (Å/s)	2.0	2.5	3.0
Chamber Pressure (Torr)	2.0×10^{-4}	2.5×10^{-4}	3.0×10^{-4}
Anode Voltage (V)	100	130	160
Anode Current (A)	1.0	2.5	3.5

Model and Its Analyses

$$\rho = \frac{R^P}{R^S} = Tan\psi \cdot e^{j\Delta} = f(n_i, k_i, d_i \cdots)$$

Measured Data

TanΨ

CosΔ

Physical Model

Estimated sample structure

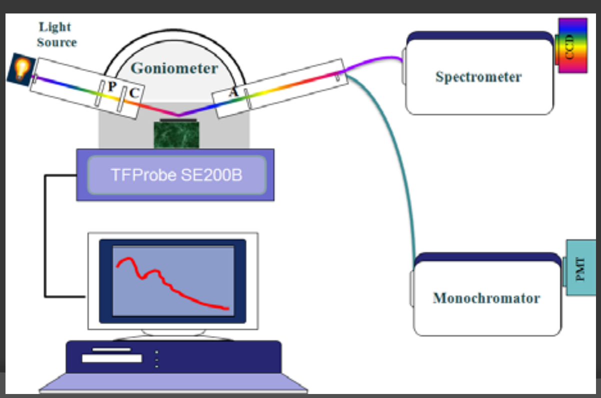
- Film Stack and structure
- Material n, k, dispersion
- Composition Fraction of Mixture

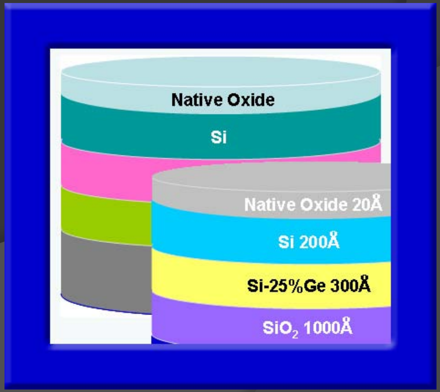
Measurement = Calculation ?

No

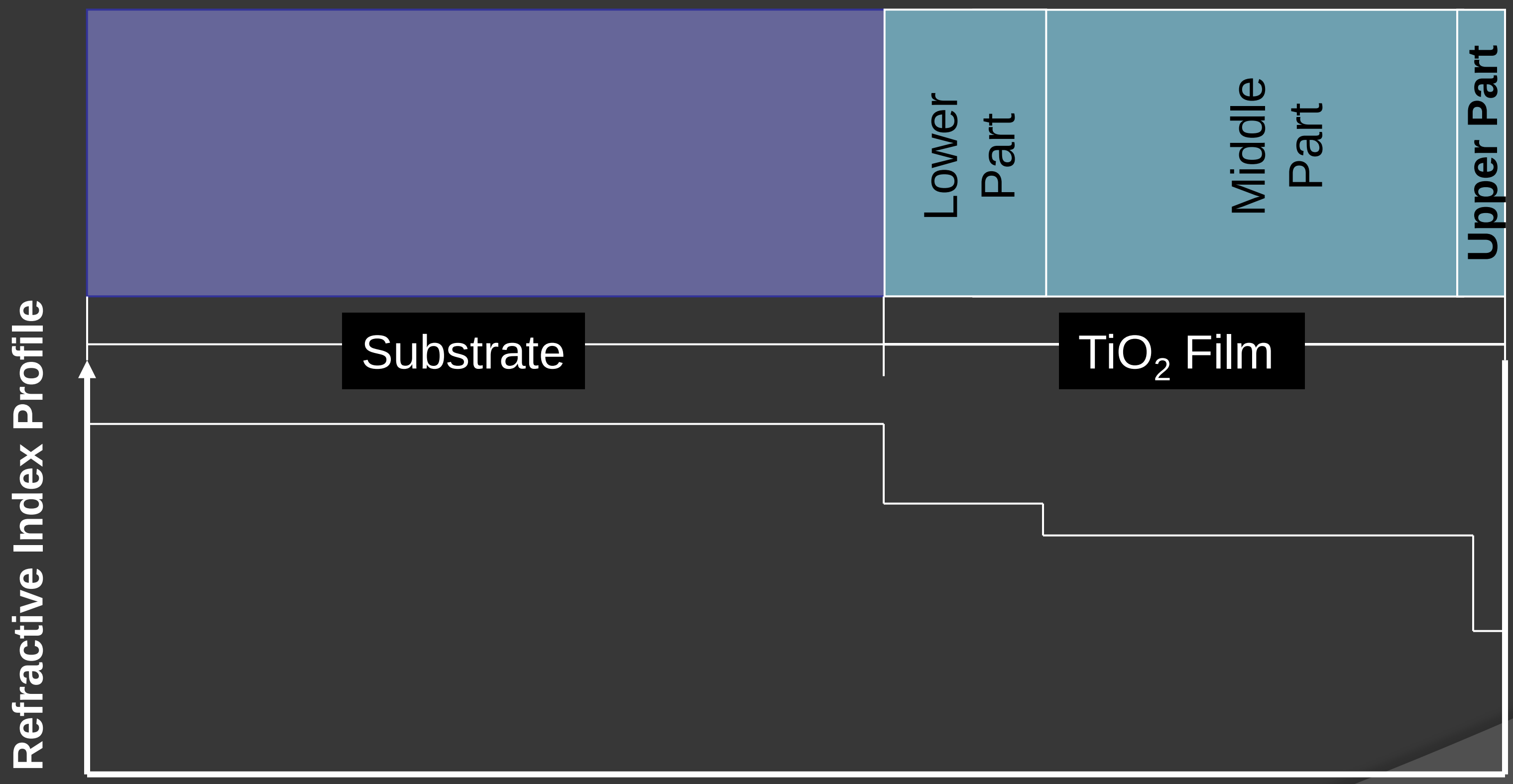
Yes

T_i, n_i, k_i

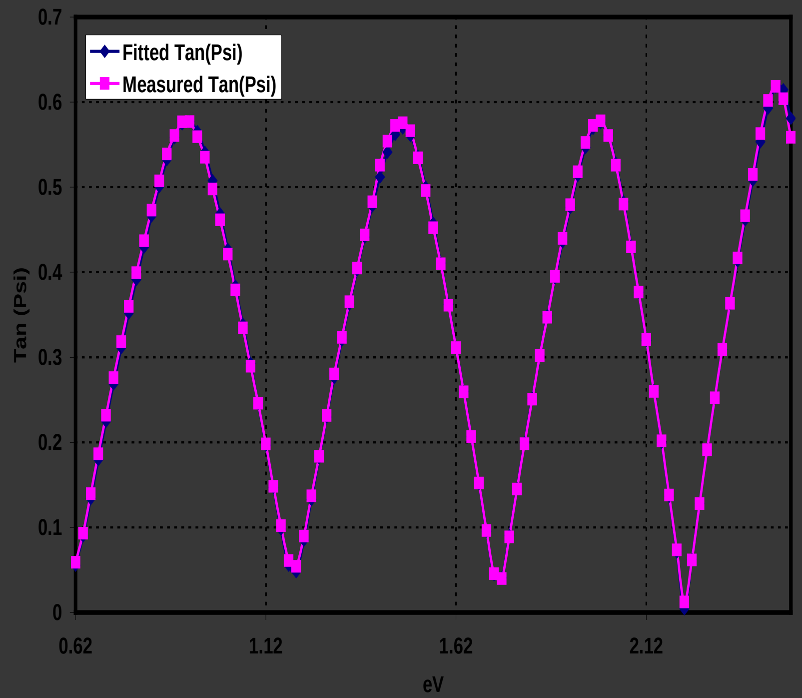


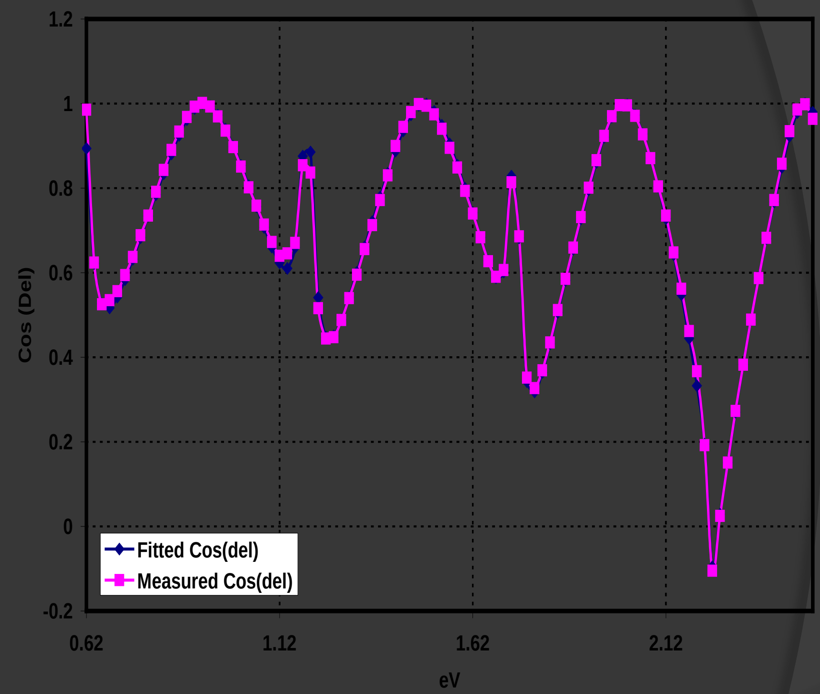


Analysis Model



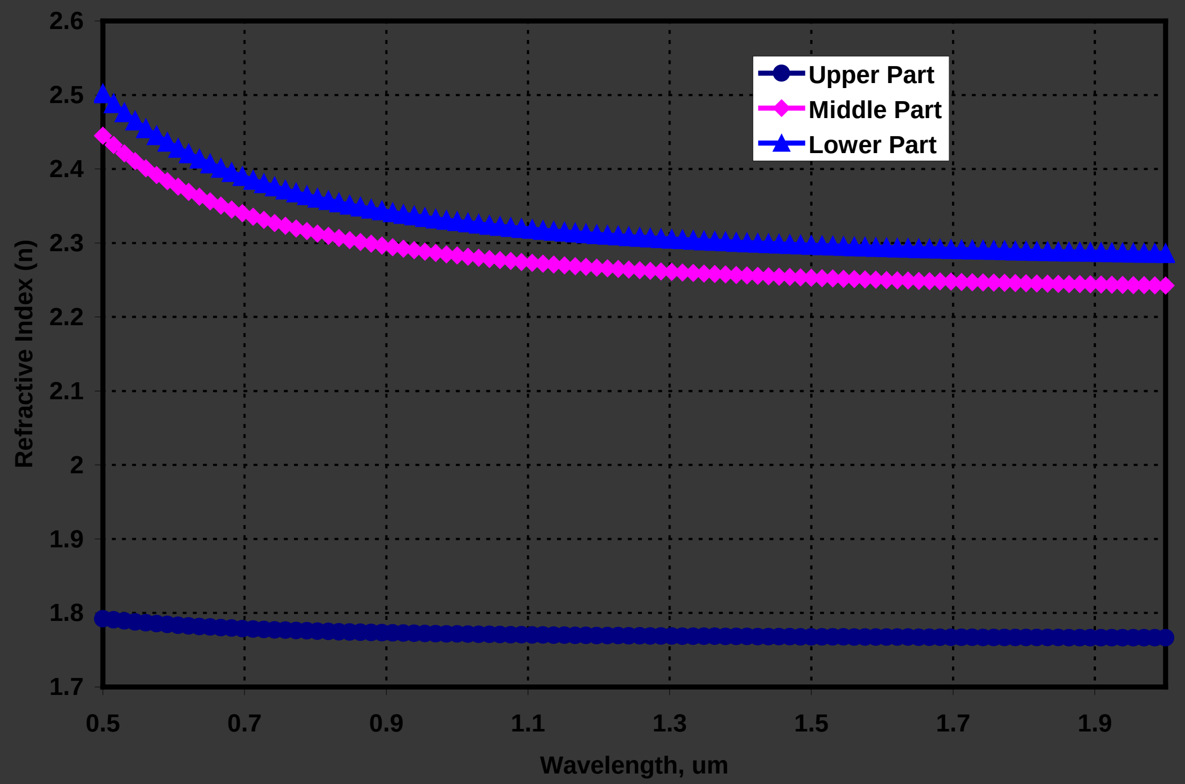
Spectra Fittings—Three Sub-Layer Model





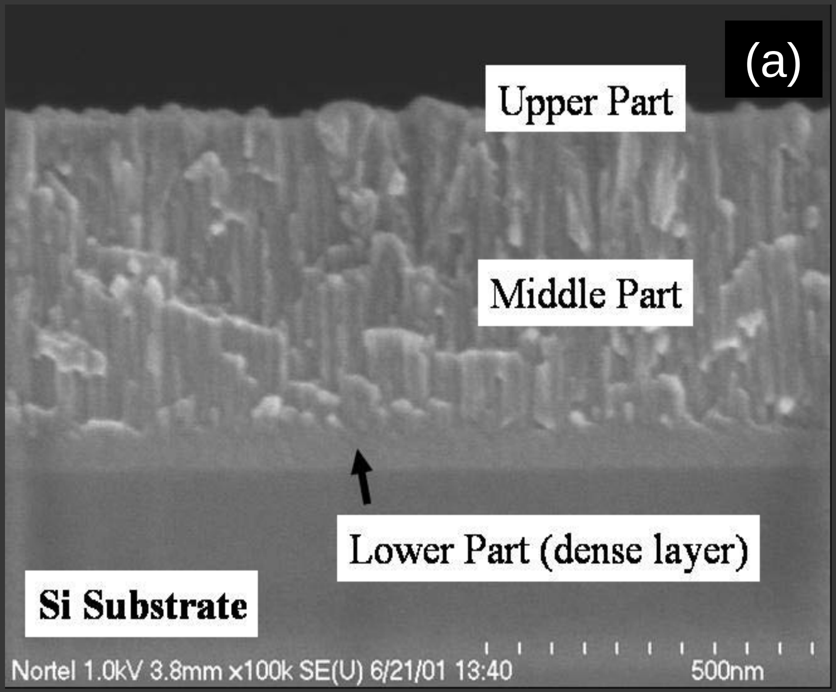
With the three Sub-layer model, the whole spectra can be successfully fitted for a as-deposited TiO_2 film, indicating a heterogeneous structure.

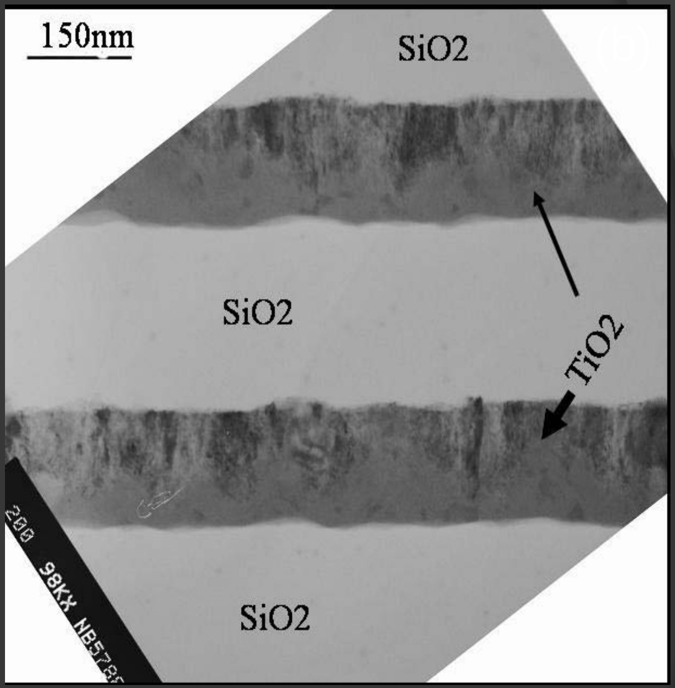
Graded Optical Constants of TiO_2 Film



Ellipsometry analysis shows the gradient refractive index from the film/substrate interface to top of the film. The typical values at 1550 nm wavelength are 1.721 (upper part), 2.2363 (middle part), and 2.2825 (lower part), respectively.

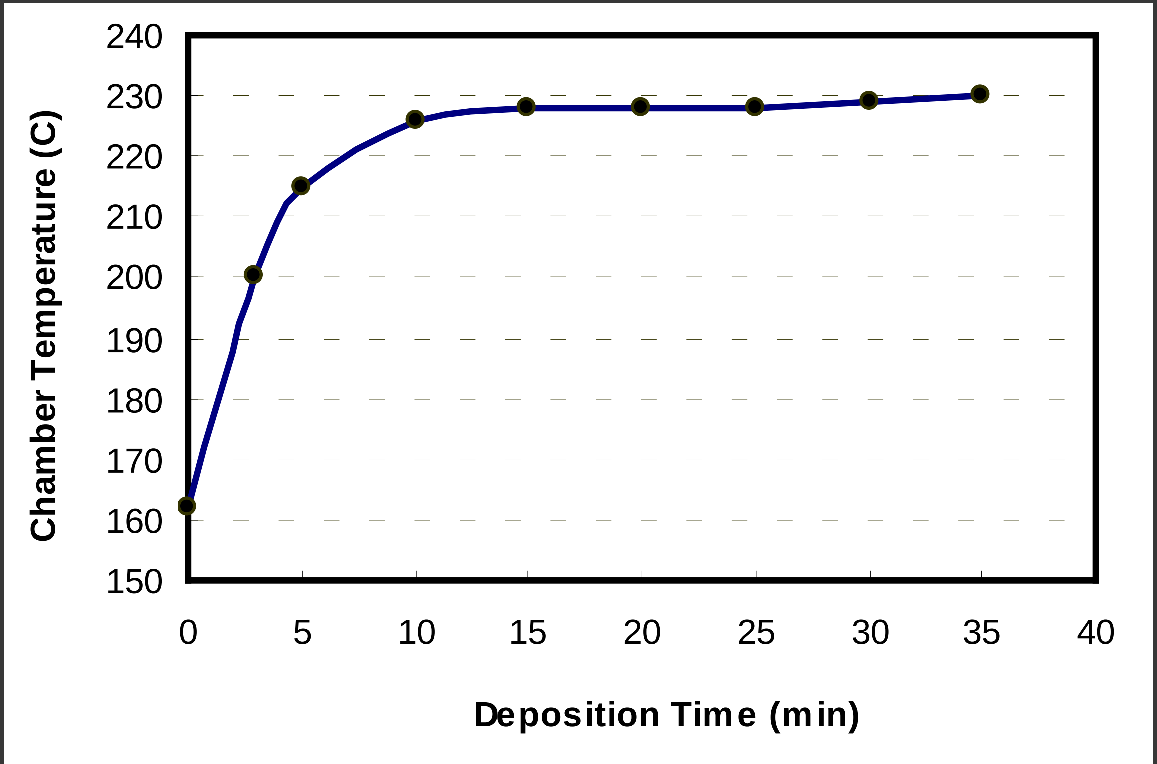
Microscope Observation





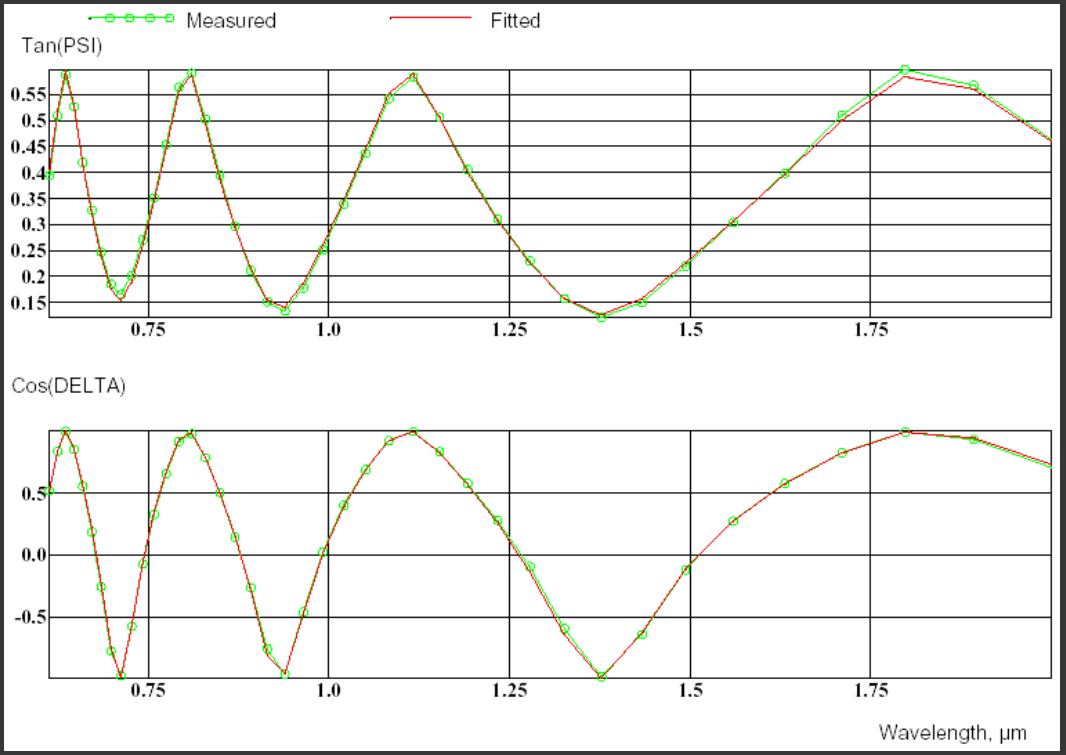
(a) SEM photo showing three sub-layers of an as-deposited TiO_2 film (left); (b) TEM photo for alternating SiO_2/TiO_2 multiple layers shows the same structure for TiO_2 single layer (right)

Chamber Temperature Variance



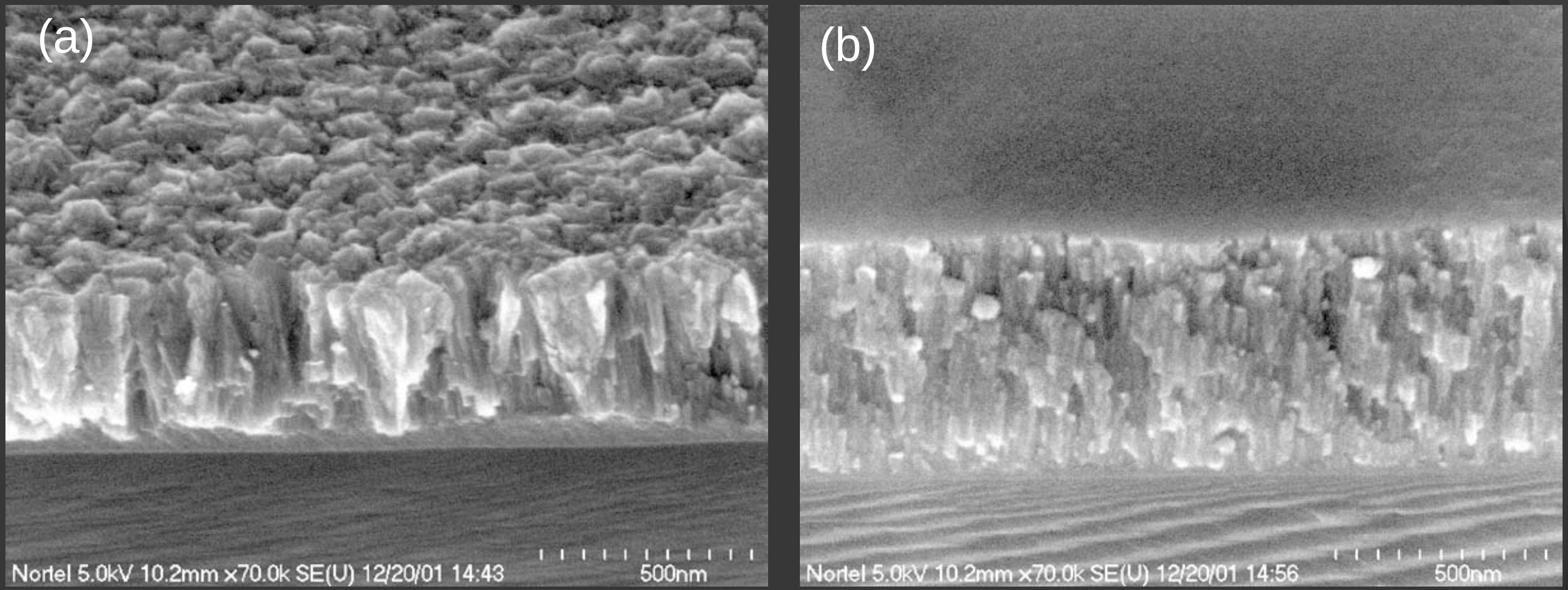
It was the temperature variance that caused the structural discrepancy of as-deposited TiO_2 film.

Co-deposited TiO_2-SiO_2 Film



Ellipsometry analysis shows an excellent fitting for a co-evaporated TiO_2-SiO_2 film with only one layer model simulation, indicating a homogeneous structure.

Surface Micrographs

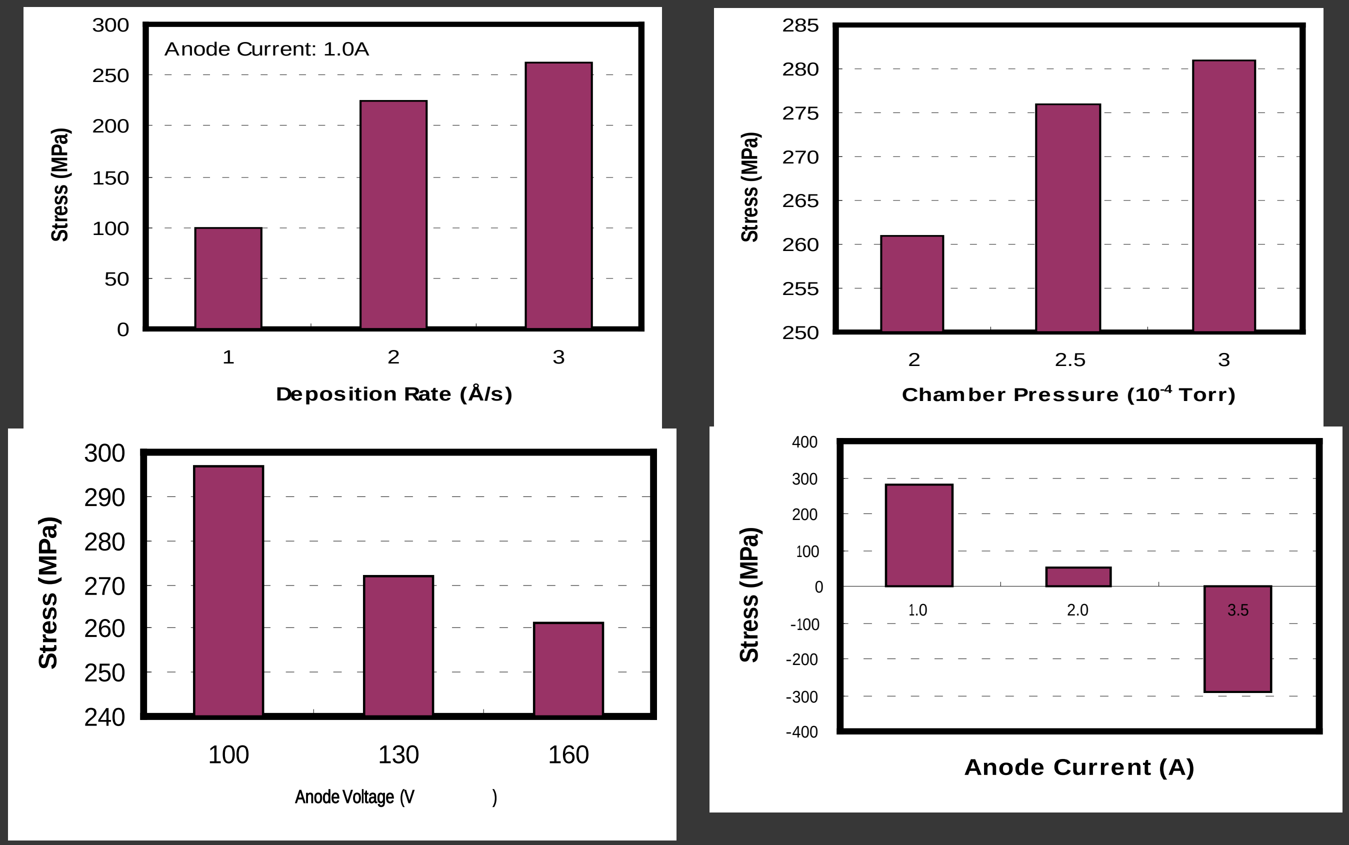


TiO_2 Film

Co-evaporated TiO_2-SiO_2 Film

SEM micrographs show (a) an as-deposited TiO_2 film (left) and (b) a TiO_2-SiO_2 co-evaporated film (right). AFM analysis shows that the surface roughness of pure TiO_2 film and co-evaporated film are 19.6 and 9.3 nm, respectively.

TiO_2 Film Stress Dependency



Any process that can increase the film packing density will result in decreasing tensile stress, or increasing compressive stress. Therefore, low deposition rate, high-energy or intensive ion bombardment will produce more compressive stress for as-deposited TiO_2 films.

NORTEL NETWORKS

Summary

- TiO_2 film stress can be tuned through properly adjusting the deposition parameters, especially anode current of the ion gun.
- Spectroscopic ellipsometry has been successfully used as a nondestructive technique to characterize the structural discrepancy of TiO_2 films.
- Three sub-layer model can be used to describe the heterogeneity of as-deposited TiO_2 films, which is caused mainly by the chamber temperature changes during the deposition.
- With TiO_2-SiO_2 co-deposition, a homogeneous film can be produced. At the same time, refractive index can be further tuned through controlling the ratio of TiO_2 to SiO_2 fraction in the film.

ACKNOWLEDGEMENT

The authors thank colleagues for SEM/TEM analyses and any other assistance