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Optical modeling of polysilicon: TOPCon PV

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NREL/PO-5900-91175

Introduction

Tunnel Oxide Passivated Contact (TOPCon)

- Utilizes n-type silicon substrate, a thin tunnel oxide, and a polysilicon layer to provide surface passivation.
- Passivation prevents defects and recombination.

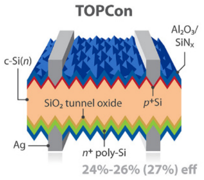

Fig 1: TOPCon solar cell

TOPCon Advantages:

- High conversion efficiency (25%)
- Better energy yields in variable weather conditions (e.g., high temperature, shade).

Research Goal:

- Determine how film thickness changes with different deposition methods.
- Analyze relationship between film thickness and optical constants.

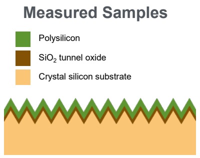

Fig 2: Polysilicon on silicon tunnel oxide on a crystal silicon substrate

Spectroscopic Ellipsometry

- Non-destructive method to determine thin-film thickness and optical properties.
- Measures a time-modulated intensity signal and determines changes in polarization.

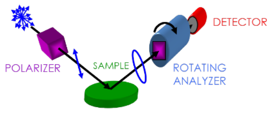

Fig 3: Interactions with the sample polarize the light. Reflected polarized light is measured by the rotating analyzer and detector.

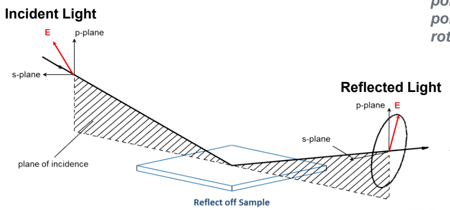

Fig 4: Polarized light traces a repeating path in the perpendicular plane (s-plane).

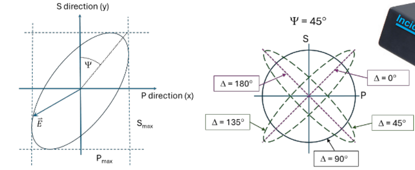

Fig 5 and 6: The relative phase difference between two orthogonal electric field components, and the amplitudes of the orthogonal electric field components, determines the shape of the ellipse.

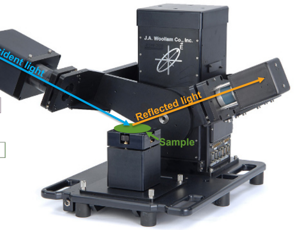

Fig 7: J.A. Woollam M-2000 Spectroscopic Ellipsometer

Methods

Bruggeman Effective Medium Approximation (EMA):

- Models the optical constants of a two-phase composite by blending the optical constants of two defined materials.
- Corresponds to a medium with varying sized spherical inclusions.

General Oscillator (Gen-OSC):

- Used to parameterize materials to model complex, amorphous, and/or unknown materials.
- Determines the optical constants of a material by manipulating absorption and dispersion parameters of a reference material.

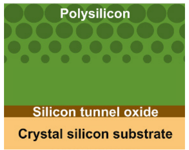

Fig 8: Sample Model

Silicon tunnel oxide:

- *Fixed thickness and optical constants*

Polysilicon:

- *EMA blends optical constants of hydrogenated amorphous silicon and crystal silicon*
- *Parameterized as general oscillator to fine tune optical constants*
- *Fitted thickness*

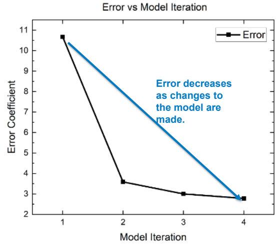

Fig 9: Lower error coefficient means better model fit

Changes with each iteration:

1. *Base EMA no optical fitting, fit film thickness*
2. *EMA fit optical constants*
3. *Parameterized as general oscillator*
4. *Added and fit for surface roughness*

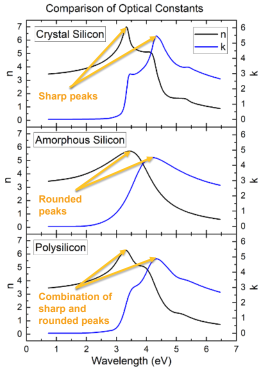

Fig 10: Polysilicon's optical constants are based on the optical constants of crystal silicon and amorphous silicon

Results

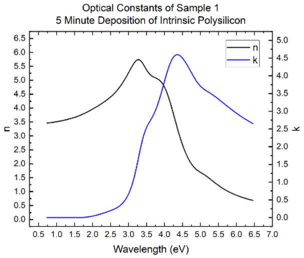

Fig 11: Sample 1 – 5 minute deposition of intrinsic polysilicon

Polysilicon thickness: 11.55 nm

Surface Roughness: 2.15 nm

Error Coefficient: 2.253

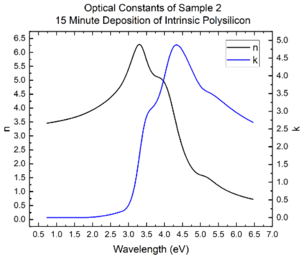

Fig 12: Sample 2 – 15 minute deposition of intrinsic polysilicon

Polysilicon thickness: 26.45 nm

Surface Roughness: 1.25 nm

Error Coefficient: 3.258

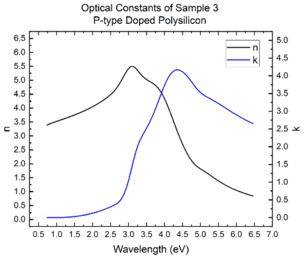

Fig 13: Sample 3 – P-type doped polysilicon

Polysilicon thickness: 29.26 nm

Surface Roughness: 2.34 nm

Error Coefficient: 2.465

TEM polysilicon thickness: ~29nm

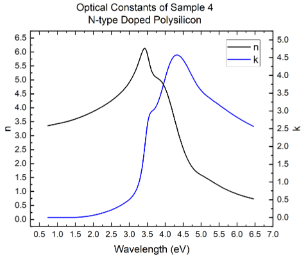

Fig 14: Sample 4 – N-type doped polysilicon

Polysilicon thickness: 28.10 nm

Surface Roughness: 1.49 nm

Error Coefficient: 3.002

Conclusions

- The deposition rate of intrinsic polysilicon is higher during initial deposition then begins to slow down as deposition time increases.
- Longer depositions of polysilicon are more crystalline in structure than shorter depositions. N-type doping of polysilicon is more crystalline in structure than P-type doping, despite similar film thicknesses.

Future Work

Deposition of alumina on top of polysilicon then annealing. Spectroscopic ellipsometry results of such work will provide further understanding of deposition rates and will help fine tune current deposition methods and equipment.

This work was supported in part by the U.S. Department of Energy, Office of Science, Office of Workforce Development for Teachers and Scientists (WDTS) under the Visiting Faculty Program (VFP). The views expressed in the article do not necessarily represent the views of the DOE or the U.S. Government. The U.S. Government retains and the publisher, by accepting the article for publication, acknowledges that the U.S. Government retains a nonexclusive, paid-up, irrevocable, worldwide license to publish or reproduce the published form of this work, or allow others to do so, for U.S. Government purposes.

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