

Atomic hydrogen induced defect kinetics in hydrogenated amorphous silicon : an in situ real time study

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the advantage of an enhanced spectral response in the red part of the solar spectrum and a better opto-electronic stability under illumination.

Since the deposition of the $\mu\text{-Si:H}$ phase under low processing temperatures ($\sim 160\text{-}250^\circ\text{C}$) is obtained by increasing the hydrogen dilution in a silane plasma, it is believed that additional flux of atomic hydrogen at the surface enhances crystalline relaxation of the silicon atoms in the lattice during growth.

With respect to photovoltaic applications of $\mu\text{-Si:H}$, high quality material is classified as dense material without any significant post-deposition oxidation, as oxidation is linked to a reduction in the red response of the $p\text{-i-n}$ solar device. This specific $\mu\text{-Si:H}$ phase has the following properties: 1) crystalline grains with a preferentially [220] oriented growth, 2) has no crystalline grain boundaries, as these internal surfaces have been identified as the location at which the unwelcome post-deposition oxidation occurs and 3) is deposited close to conditions in which the growth transfers from amorphous to microcrystalline.

In this contribution we will address in detail the material properties of $\mu\text{-Si:H}$ and its relation to its performance in solar cells, the growth mechanism of the $\mu\text{-Si:H}$ phase under plasma deposition conditions and the crucial role of the control of plasma processing in obtaining device grade material. Finally, we will discuss the upscaling of the deposition technology (high deposition rates over large areas), which is an important issue in substantially reducing the cost-price of thin silicon photovoltaic products. We will present the recently explored deposition regime at higher processing pressures ($\sim 5\text{-}25$ Torr), which has a high potential to bring about this important breakthrough in the thin silicon film photovoltaic technology.

10:40am **PS2+PV-MoM8 Atomic Hydrogen Induced Defect Kinetics in Hydrogenated Amorphous Silicon: An In Situ Real Time Study**, *M.C.M. van de Sanden, F.J.J. Peeters*, Eindhoven University of Technology, The Netherlands, *J. Zheng*, Peking University, China, *I.M.P. Aarts*, ASML, The Netherlands, *A.C.R. Pipino*, Tanner Research, *W.M.M. Kessels*, Eindhoven University of Technology, The Netherlands

Near-IR Evanescent-Wave Cavity Ring-Down Spectroscopy (EW-CRDS) is applied to an a-Si:H thin film subjected to quantified H fluxes from an atomic H source in the range of $(0.4\text{-}2)\times 10^{14}\text{ cm}^{-2}\text{s}^{-1}$. To this end 20-80 nm a-Si:H films were grown on the Total Internal Reflection (TIR) surface of a folded miniature optical resonator by thermal decomposition of silane on a hot filament. Measurements are performed over a temperature range of 80–200 °C. The observed changes in the optical loss during H dosing of a-Si:H are attributed to the creation and healing of sub-gap Dangling Bond (DB) defect states and were measured with a sensitivity of $\sim 10^6$ and a time resolution of 33 ms. The DB density is shown to increase during H dosing cycles and the DBs reversibly 'heal' when the H flux is terminated. The effect increases in magnitude with H flux and decreases with temperature. Through the use of polarizing optics the CRDS signal was split into s- and p-polarized components, which, combined with field calculations, revealed that H-induced DB formation is not limited to the surface of the film but progresses into the bulk with a penetration depth of ~ 10 nm. Due to their limited lifetime the created DB defects are identified as the result of H insertion into strained Si-Si bonds in the bulk material. Extensive kinetic modeling of this process is used to determine activation energies for the hydrogen-material interactions and DB formation in a-Si, which are of key importance in a-Si:H thin film solar cells. Moreover the implications of this study for Eley-Rideal type reactions on the surface and hydrogen exchange reactions in the bulk will be addressed.

11:00am **PS2+PV-MoM9 Hydrogen-dominated Plasma, Due to Silane Depletion, for Microcrystalline Silicon Deposition**, *A.A. Howling, R. Sobbia, Ch. Hollenstein*, EPFL Lausanne, Switzerland **INVITED**

Plasma conditions for microcrystalline silicon deposition generally require a high flux of atomic hydrogen, relative to SiH_x radicals, on the growing film. The necessary dominant partial pressure of hydrogen in the plasma is conventionally obtained by hydrogen dilution of silane in the flow inlet. However, a hydrogen-dominated plasma environment can also be obtained due to plasma depletion of the silane in the gas mixture, even up to the limit of pure silane inlet flow, provided that the silane depletion is strong enough. At first sight, it may seem surprising that the composition of a strongly-depleted pure-silane plasma consists principally of molecular hydrogen, without significant contribution from the partial pressure of silane radicals. The aim here is to bring some physical understanding by means of a zero-dimensional, analytical plasma chemistry model. The model is appropriate for uniform, large-area showerhead reactors as shown by comparison with results of three-dimensional numerical simulations. The SiH_x densities remain very low because of their rapid diffusion and surface reactivity, contributing to film growth which is the desired scenario for efficient silane utilization. Significant SiH_x densities due to poor design of reactor and gas flow, on the other hand, would result in powder formation wasting silane. Conversely, hydrogen atoms are not deposited, but associate on the film

surface and re-appear as molecular hydrogen in the plasma. Therefore, in the limit of extremely high silane depletion fraction ($>99\%$), the silane density falls below the low SiH_x densities, but only the H radical can eventually reach significant concentrations in the hydrogen-dominated plasma.

11:40am **PS2+PV-MoM11 Plasma Uniformity Measurements in a Scalable, Multi-Electrode, VHF/UHF Plasma Source**, *D. O'Farrell, A.R. Ellingboe, S. Linnane, C. Gaman*, Dublin City University, Ireland

The ability to deposit large area thin film amorphous silicon films using PECVD is of significant interest in a number of fields including photovoltaics and flat panel display. The desire to deposit larger area films faster has led to a recent push towards the use of VHF/UHF frequencies which result in faster deposition rates but also result in significant film non-uniformities due to wavelength effects even over relatively small areas. Several methods have been employed in an attempt to overcome these non-uniformity issues but many barriers still exist when it comes to wide scale application. In this work a scalable, multi-electrode, VHF/UHF plasma source is described which aims to resolve these issues. Data is presented demonstrating plasma uniformity over the source for a series of powers, pressures and operating frequencies. Different operating regimes are discussed.

Advanced Surface Engineering
Room: B1 - Session SE1-MoM

Photocatalytic Coatings

Moderator: H. Barankova, Uppsala University, Sweden

8:20am **SE1-MoM1 Development of Highly Functional Visible Light-responsive TiO_2 Thin Film Photocatalyst Materials by a RF Magnetron Sputtering Method and their Applications for our better Environment and Production of Clean Energies using Sunlight**, *M. Anpo, M. Matsuoka, M. Takeuchi*, Osaka Prefecture University, Japan **INVITED**

Titanium oxide-based catalysts have attracted a great deal of attention for their application in photocatalytic materials with high reactivity, thermal stability and nontoxic properties¹. However, unlike natural photosynthesis in green plants, they can make use of only 3-4% of solar light, necessitating the use of a UV light source. Recently, we have successfully applied a RF magnetron sputtering deposition method to design unique and efficient titanium oxide photocatalysts which enable the absorption of visible light of longer than 550 nm. These newly developed titanium oxide catalysts were found to work as environmentally-friendly photocatalyst, leading to the efficient use of solar energy for the production of clean H_2 and O_2 from water with a separate evolution and other significant reactions²⁻⁴.

In the present lecture, the results obtained for the photocatalytic decomposition of H_2O with the separate evolution of H_2 and O_2 under sunlight irradiation of the visible light-responsive titanium oxide thin film photocatalysts will be presented.

References

- 1) M. Anpo, et al., in "Annu Rev. Mater. Res.", Eds. J. M. Thomas and P. L. Gai, **35**, 1 (2005).
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- 3) M. Kitano, M. Matsuoka, J. M. Thomas, M. Anpo, et al., *Top. Catal.*, **49**, 24 (2008).
- 4) S. Fukumoto, M. Kitano, M. Takeuchi, M. Matsuoka, M. Anpo, *Catal. Lett.*, **127**, 39 (2009).

9:00am **SE1-MoM3 The Effect of Nb Additions on the Synthesis, Photo-Response, and Photo-Activity of TiO_2 Thin Films**, *P.A. DeSario, M.E. Graham, K.A. Gray*, Northwestern University

A deeper understanding of the relationships between synthesis, structure and function is needed to improve the design of materials tailored to solar energy conversion and storage. The objective of this research is to synthesize TiO_2 composites with properties tailored to the harvesting and conversion of solar energy. Unbalanced reactive dc magnetron sputtering with partial pressure control of oxygen was utilized to synthesize a series of pure and mixed phase TiO_2 films. Films were doped with Nb ($\text{Ti}_{1-x}\text{Nb}_x\text{O}_2$) in the range of $0 < x < 0.45$ to evaluate the effect of cation doping on optical, chemical and physical properties. The films were interrogated structurally and functionally using SEM, EDX, XPS, AFM, UV-Vis absorption spectroscopy, and XRD. Selected films were evaluated with respect to gas