Reactive pulsed laser deposition of amorphous hydrogenated silicon thin films for solar cell applications

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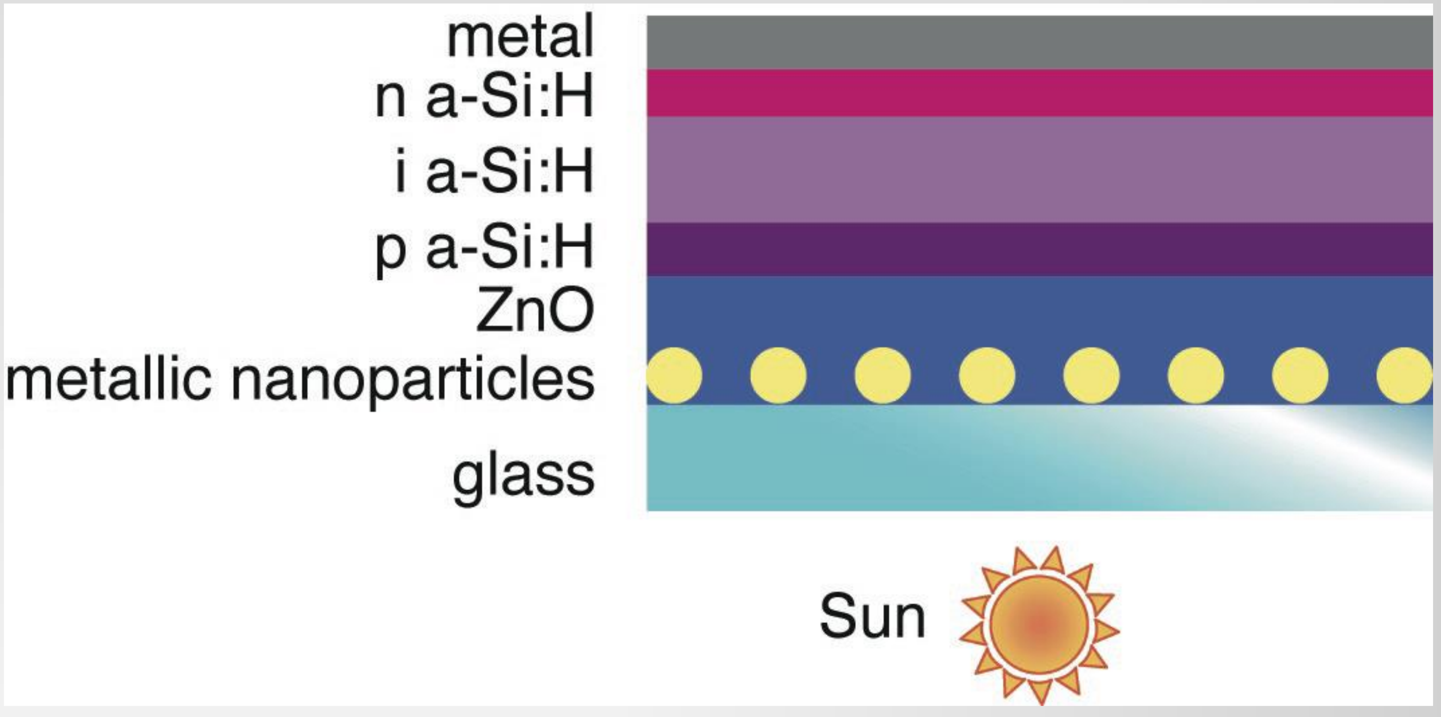
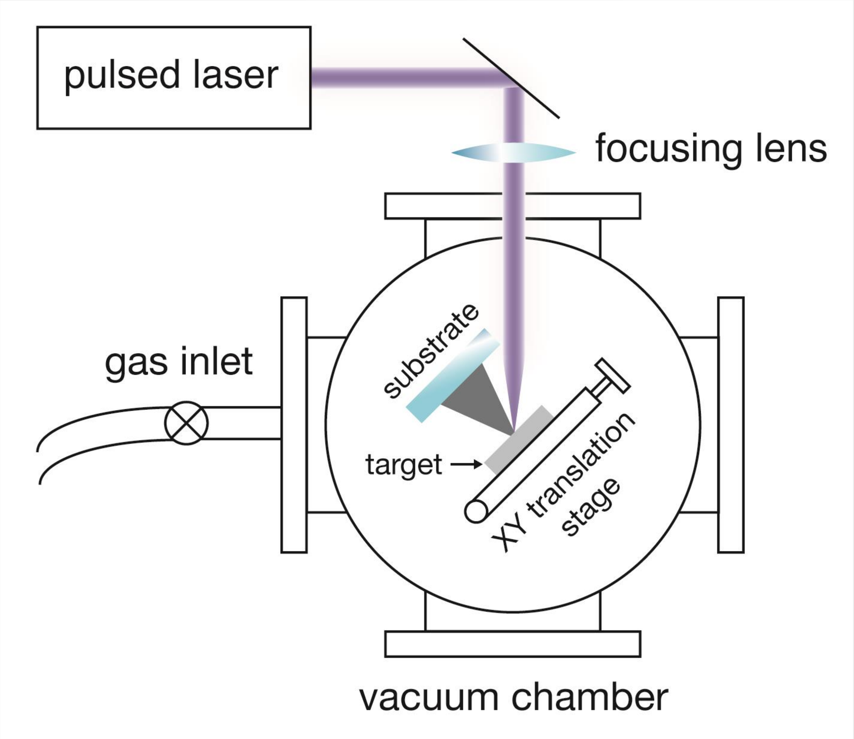
Abstract

Amorphous hydrogenated Si (a-Si:H) thin-film solar cells offer power conversion efficiencies up to 12% and use the advantages of the existing Si infrastructure, therefore they are of high technological interest. We employ pulsed laser deposition for the fabrication of a-Si:H solar cells in the p-i-n configuration for increased efficiency. The efficiency of the solar cells can be further improved by the incorporation of metallic nanoparticles for increased light absorption [1,2]. We irradiate silicon targets by a large number of laser pulses produced by an Nd:YAG laser system (10 ns pulse duration), operating at 355 nm, in hydrogen atmosphere. Varying the PLD parameters, such as the laser fluence, number of pulses, substrate temperature, and hydrogen pressure, we optimize the morphology, electric conductivity, and optical properties of the a-Si:H layers for maximum efficiency. The doping level of the a-Si:H layers can be further controlled by the simultaneous irradiation of the silicon target and a doping target by two synchronized lasers [3].

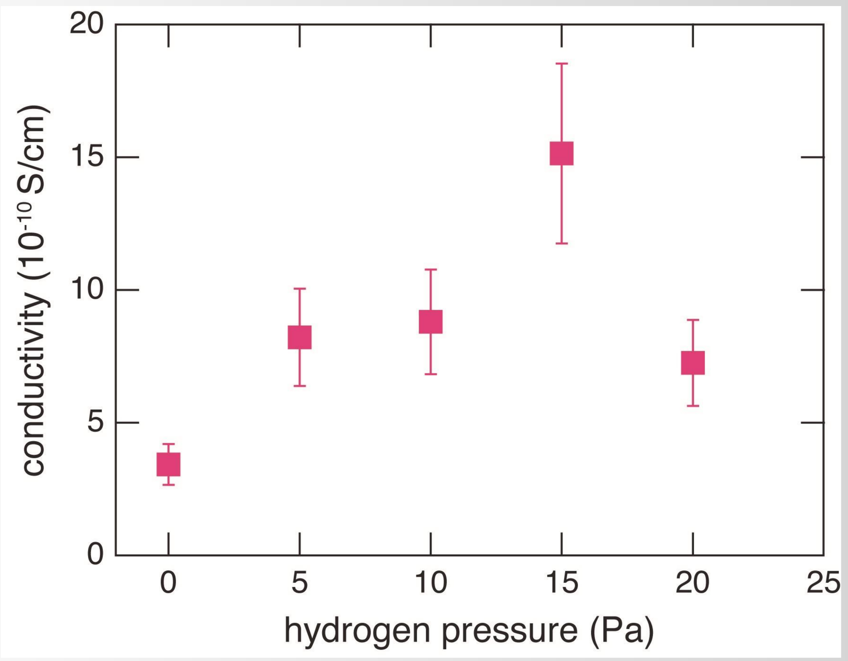


Pulsed Laser Deposition



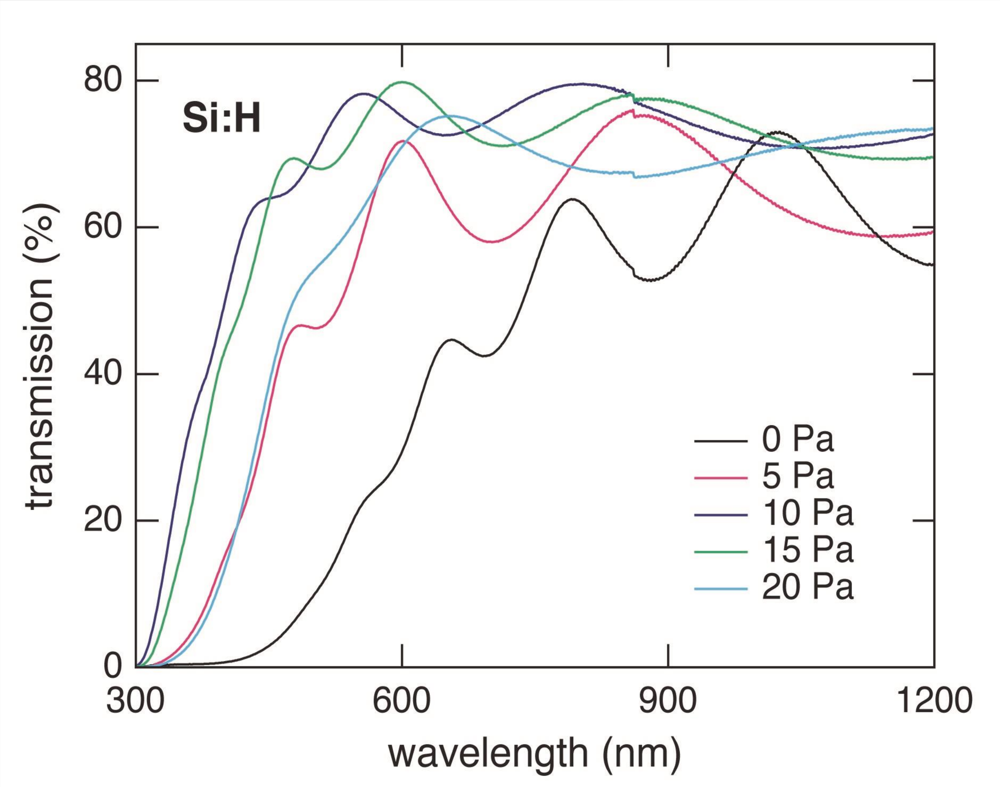
- Pulsed laser deposition of Si targets in a reactive hydrogen environment.
- Nd:YAG laser system, 10 ns pulse duration, 355 nm operating wavelength.
- Hydrogen pressure optimized for optical and electric characteristics.
- Formation of i-Si:H, n-Si:H, and p-Si:H thin films.
- Structural, optical, and electric properties of Si:H thin films efficiently optimized.
- Pulsed laser deposition of ZnO with Au nanoparticles as the transparent electrode.

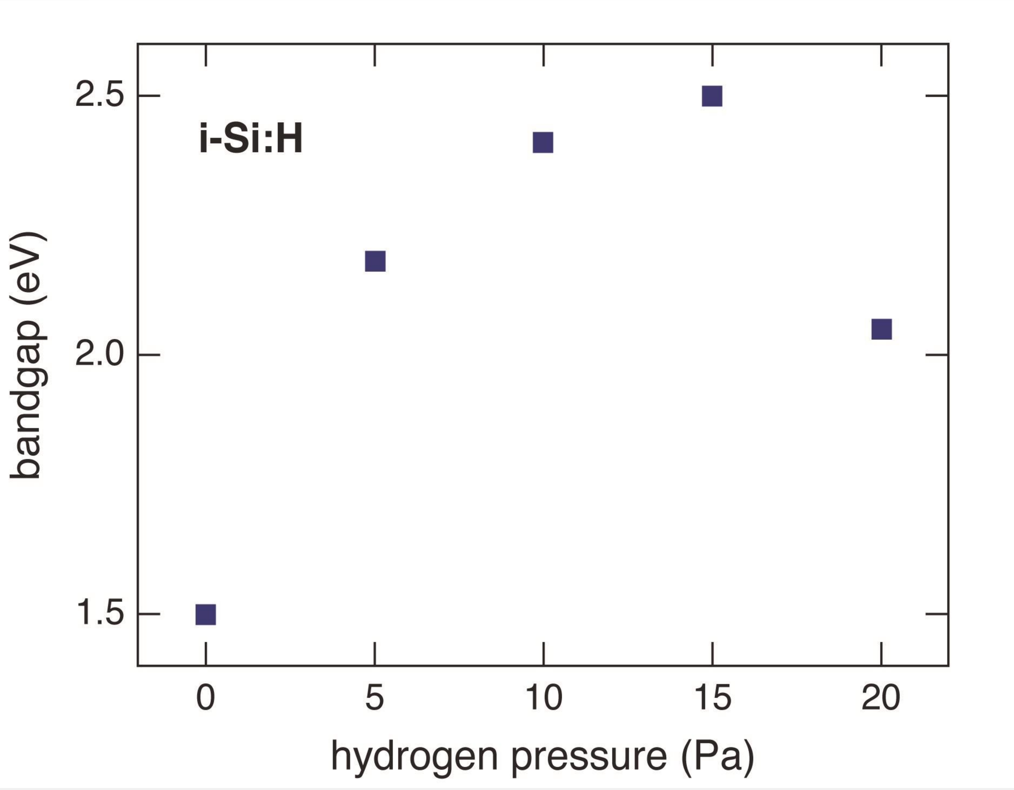
Electric properties



- Deposition of intrinsic Si:H thin films (i-Si:H) with varying hydrogen pressure.
- Deposition parameters: laser fluence 13 mJ/cm^2, substrate temperature 120^{o}C, 3 hrs deposition time, glass and silicon substrates.
- Electric conductivity increases with hydrogen pressure, up to 15 Pa.

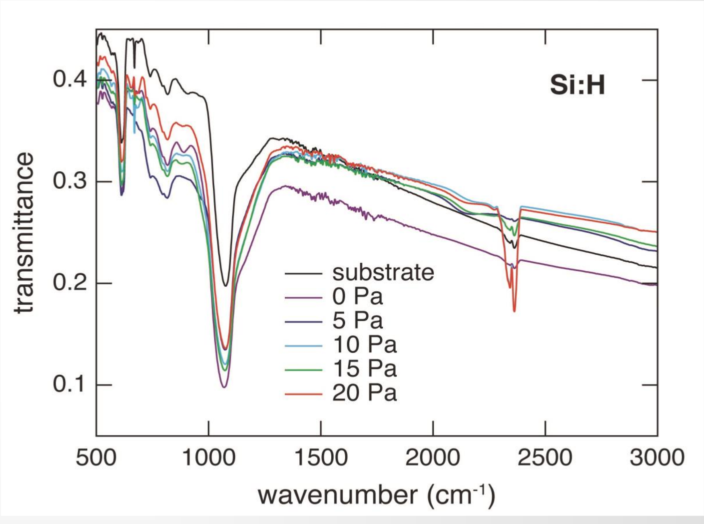
Optical properties

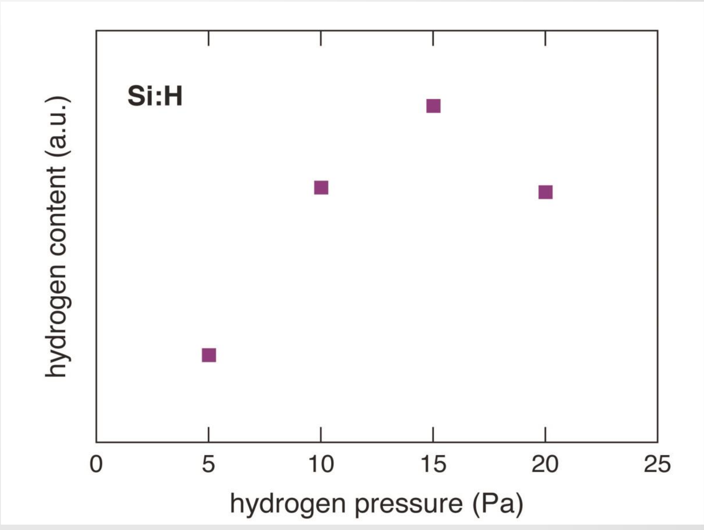




- Intrinsic Si:H thin films were deposited with pulsed laser deposition for different hydrogen pressures in the vacuum chamber.
- Optical transmission spectra were recorded in the 300 – 1200 nm range with a UV-Vis spectrophotometer.
- The transmission of the samples presents interference fringes from multiple reflections on the front and back side of the films. Multiple fringes are present for all samples due to the thickness of the films.
- From optical transmission and reflection measurements we calculated the absorption coefficient of the films, assuming they behave as direct semiconductors, and with the aid of a Tauc plot we were able to determine the optical bandgap.
- The optical bandgap increases with increasing hydrogen pressure during deposition, until it reaches a maximum value and then starts decreasing towards lower values.
- The presence of hydrogen in Si:H films is known to reduce Si dangling bonds, which create midgap electronic states. Therefore, by the reduction of these states, the optical bandgap increases.
- Excessive hydrogen during deposition extracts H atoms from the surface of the deposited films, thus reducing the hydrogen content of the material, which in turn results in a decrease of the bandgap.
- The intrinsic layer acts as the solar radiation absorber in a p-i-n solar cell.

IR spectroscopy





- IR transmission measurements on Si:H thin films deposited on Si substrates.
- IR data indicate Si-O, Si-Si, and Si-H bonds.
- The peak at 2150 cm^{-1} corresponds to Si:H bonds. It only appears for the hydrogenated Si films.
- Based on the IR measurements, we estimate the proportional amount of hydrogen in the Si:H films.

- The amount of hydrogen is proportional to the area of the 2150 cm^{-1} peak.
- The hydrogen content of the films decreases beyond a certain hydrogen pressure during deposition, because excessive hydrogen removes H atoms from the surface of the films .
- The IR data are in agreement with the optical data.

Conclusions

- Pulsed laser deposition was employed for the fabrication of hydrogenated silicon thin films for solar cell applications .
- Intrinsic Si:H films were deposited for various hydrogen pressures during deposition.
- The thickness of the films decreases with increasing hydrogen pressure, due to collisions of Si particles with H atoms and scattering of Si during deposition.
- The optical bandgap of the films increases with hydrogen pressure due to passivation of Si dangling bonds and removal of midgap states.
- Excessive hydrogen pressure during deposition results in reduced hydrogen content in the films, which decreases the optical bandgap.

References

1. J.-L. Wu *et al.*, "Surface plasmonic effects of metallic nanoparticles on the performance of polymer bulk heterojunction solar cells," *Nano* **5**, 959 (2011).
2. O.N. Gadomsky, K.K. Altunin, N.M. Ushakov, and D.M. Kulbackii, "Giant photovoltaic effect," *JETP Lett* **93**, 353 (2011).
3. I. Fasaki, M. Kandyla, M.G. Tsoutsouva, and M. Kompitsas, "Optimized hydrogen sensing properties of nanocomposite NiO:Au thin films grown by dual pulsed laser deposition," *Sensor Actuat B-Chem* **176**, 103 (2013).

Acknowledgements

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