Effect of oxide thin films in back contact on optical absorption efficiency of thin crystalline Si solar cells

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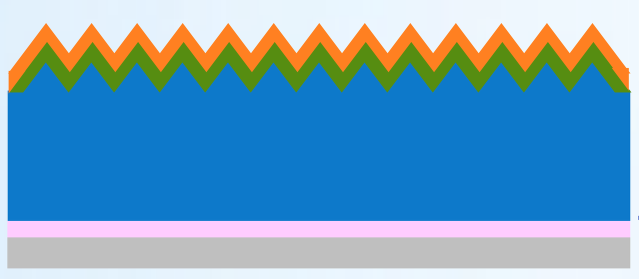
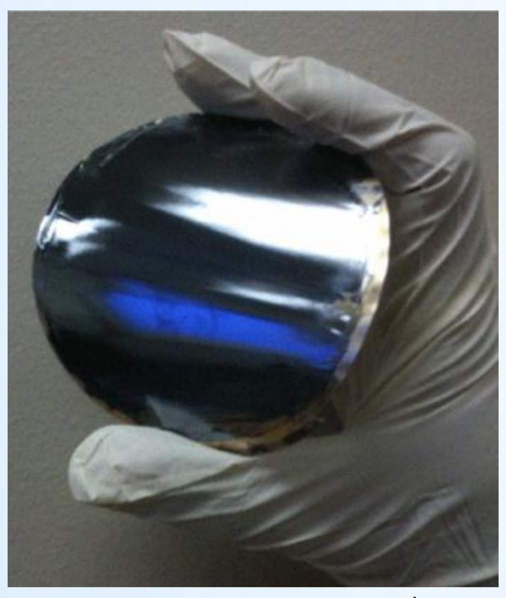
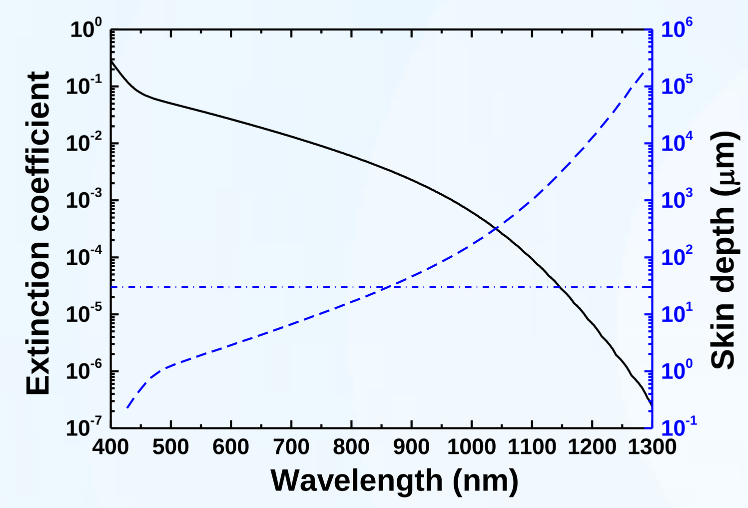
Background & motivation

Development of thin c-Si solar cells





J. G. Fossum *et al.* PVSC (2010) 35th IEEE



- **Low absorption due to thin c-Si**
- **To improve light absorption efficiency**
  - **Texturing of front surface & AR coating**
  - **Double-layered (oxide/metal) back contact**
- **Examine the effect of oxide layer**

Simulation conditions

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- Accurate
- Direct calculation of optical absorption energy

Coherent region

$$[M] = \begin{bmatrix} \cos\delta & i\frac{\sin\delta}{Y_f} \\ iY_f \sin\delta & \cos\delta \end{bmatrix}$$

phase diffence: $\delta = \frac{2\pi}{\lambda} N d \cos\theta$, admittance: $Y_f = \frac{H_f}{E_f}$

Incoherent region

$$\Phi(x,\lambda) = \Phi^0(0,\lambda)\exp(-\alpha(\lambda)x) \quad \Phi^0(\lambda) = P(\lambda)\frac{\lambda}{hc}$$

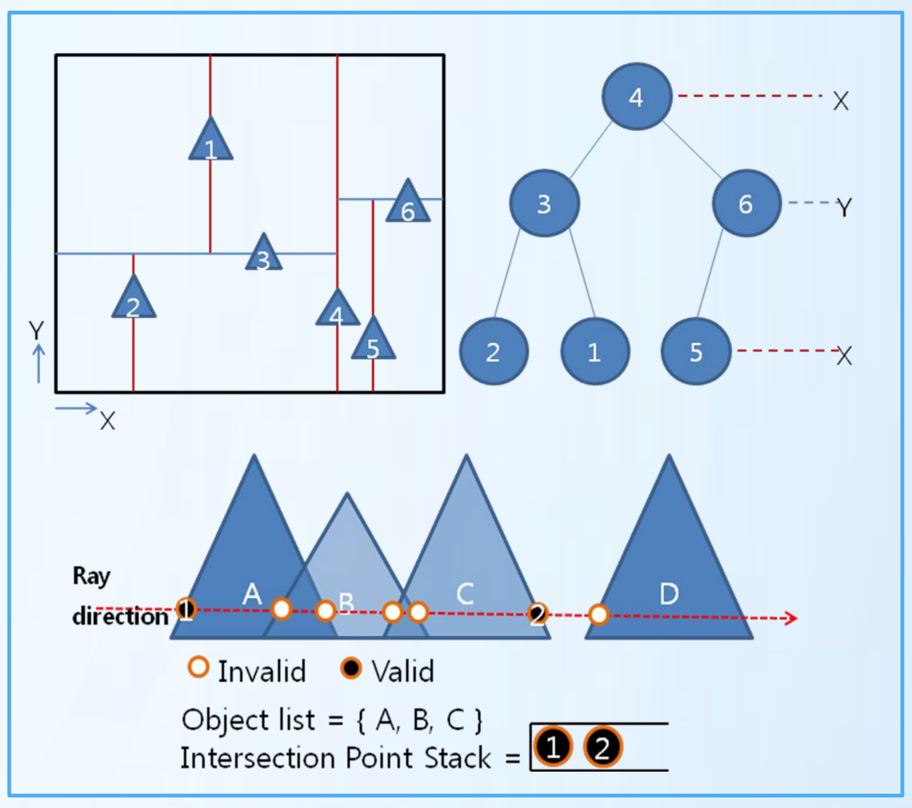
$$\Phi_{Absorption}(\lambda) = \sum_{n=1}^{n=traced\ ray\ numbers} \Phi_{Absorption}(n,\lambda)$$

All system region

- ✓ Snell's Law by complex IOR
- ✓ Fresnel Equations with complex IOR
- ✓ BSDF
- ✓ Coating Information (ex: anti-reflection)

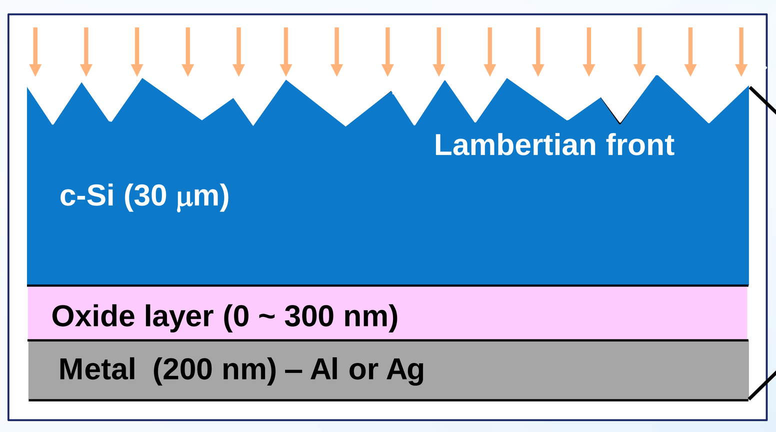
S.-J. Byun *et al.* Solar Energy Mater. Solar Cells (2011)

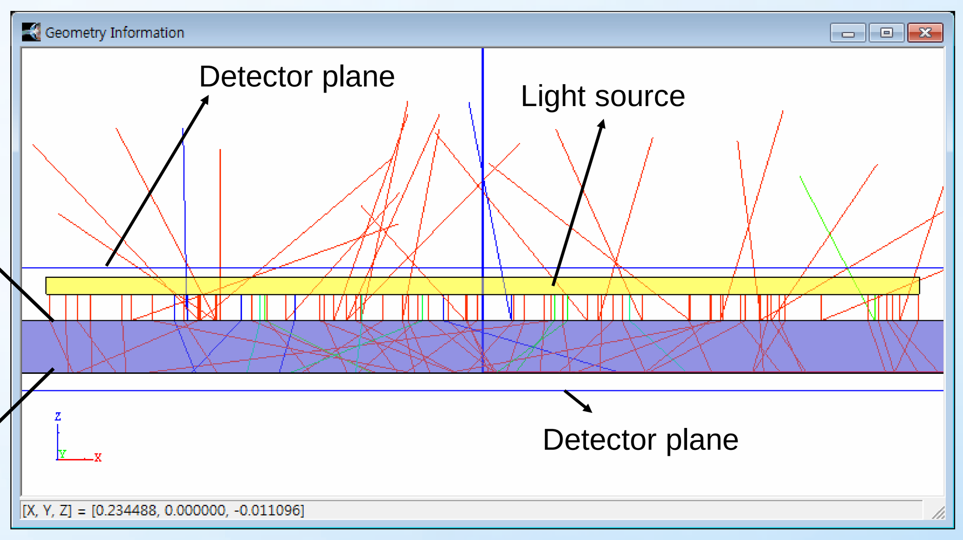
Slab-online algorithm
- Efficient logic for fast computing time



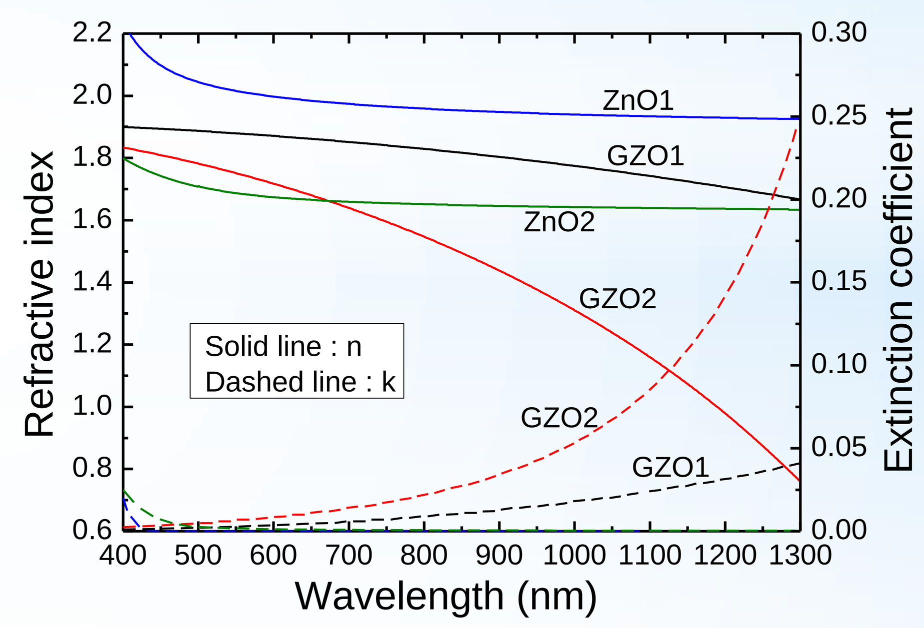
S.-Y. Byun *et al.* J. Nanosci. Nanotech. (2012)

Simulation scheme





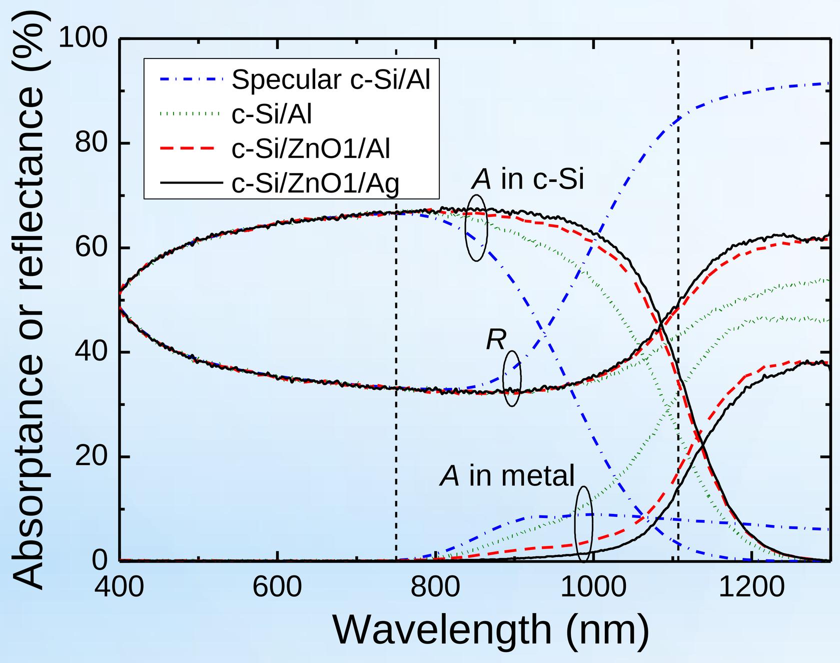
Materials

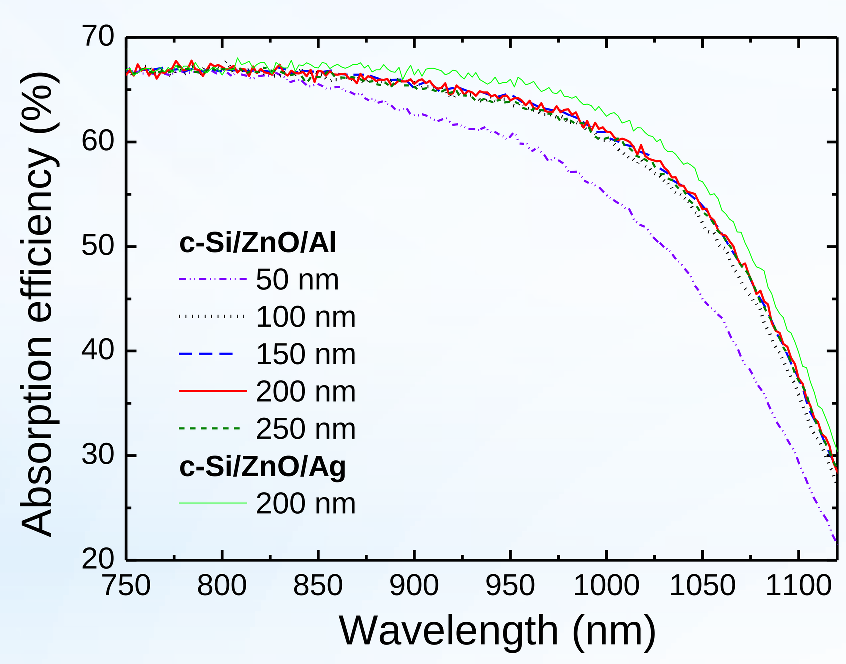


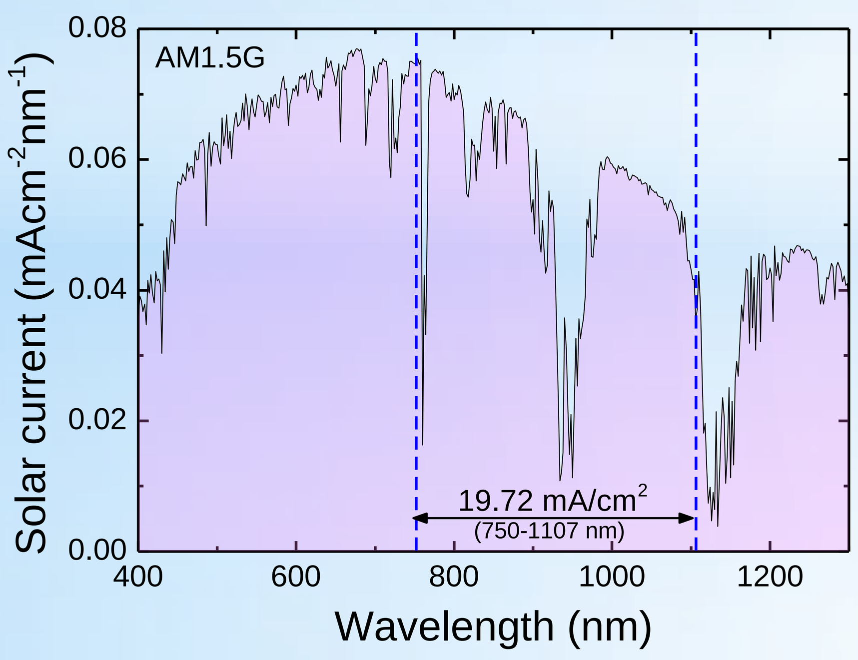
Oxide films
- **ZnO1 : Intrinsic ZnO**
- **ZnO2 : Intrinsic ZnO deposited in oblique incidence sputtering**
- **GZO1 : Ga doped (n=1.7x10^{20} cm^{-3})**
- **GZO2 : Ga doped (n=8.6x10^{20} cm^{-3})**
- **GZO3 : Refractive index of GZO2 but with zero extinction coefficient**

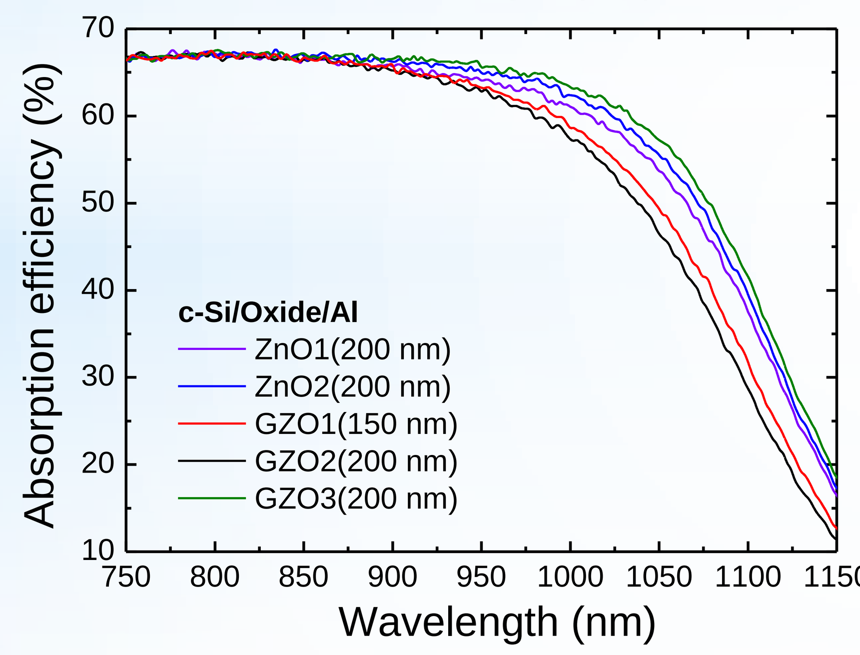
Refractive index
ZnO1>GZO1>ZnO2>GZO2=GZO3
Extinction coefficient
GZO2>GZO1>ZnO1=ZNO2=GZO3=0

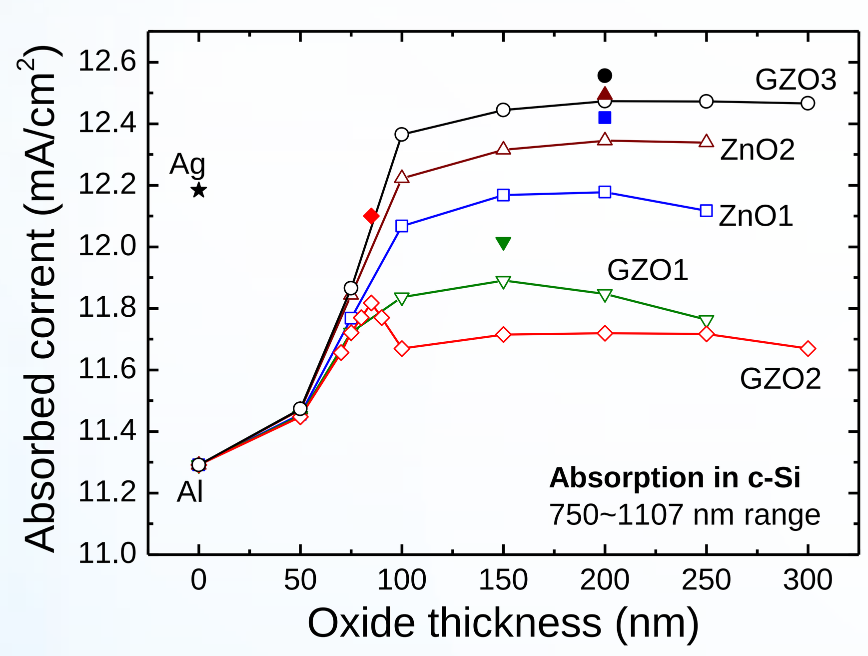
Results

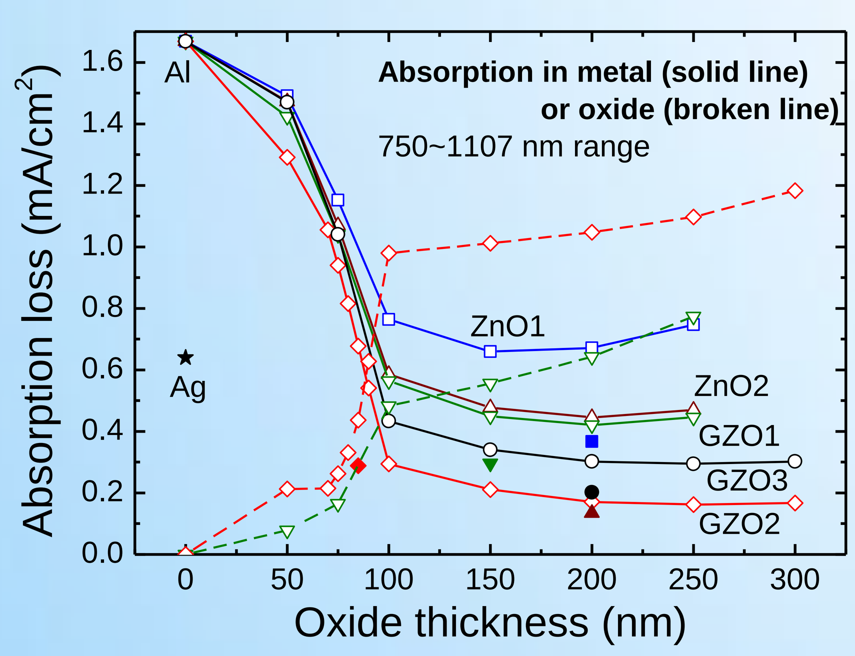


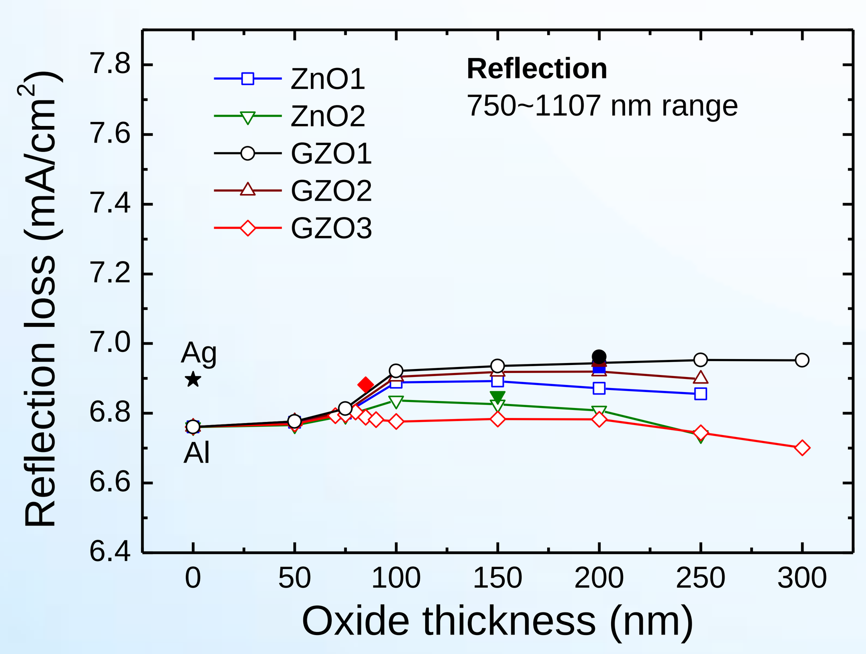












Conclusions

- **The optical absorption efficiency (OAE) of thin crystalline Si (c-Si) solar cells was examined by using a direct absorption calculation algorithm based on the three-dimensional modeling and ray-tracing technique.**
- **The back contact was assumed to be made of ZnO based oxide layers with different optical constants and metallic electrode, and the front surface was assumed to be Lambertian.**
- **Insertion of non-absorptive oxide layer between c-Si and Al improved OAE, and the relative amount of enhancement increased with decreasing refractive index, manifesting the reduction in absorption loss in Al electrode due to the increased total internal reflection.**
- **In the case of absorptive oxide layer, although increase in OAE was still attainable when compared with back contact without oxide, the OAE was subdued significantly due to large absorption loss in oxide layer.**
- **The optimal oxide layer thickness was around 200 nm for non-absorptive oxide, and that of absorptive oxide decreased with increasing extinction coefficient.**
- **In the case of Ag metal contact, the enhancement of OAE due to use of oxide layer was much less than the case of Al because of inherent high reflectivity and low absorption loss in Ag layer.**

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