CIGS THIN-FILM SOLAR CELLS AND THEIR MODELLING IN ANSYS LUMERICAL: PROSPECTS FOR ENERGY-EFFICIENT DEVELOPMENT OF UZBEKISTAN'S REGIONS

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Annotatsiya. Maqolada O'zbekistonda yangi avlod CIGS yupqa plyonkali quyosh elementlarining mintaqa iqtisodiyoti uchun ahamiyati tahlil qilingan. CIGS elementlarining tuzilishi va rekord natijalari ko'rib chiqilgan. Quyosh elementlarini kompyuterda modellashtirishning zamonaviy tendensiyalari hamda ANSYS Lumerical dasturining optik, elektr va issiqlik jarayonlarini birgalikda modellashtirishdagi o'rni yoritilgan. Mahalliy ilmiy salohiyat va kadrlar tayyorlash bo'yicha takliflar berilgan.

Kalit so'zlar: CIGS quyosh elementi, yupqa plyonka, modellashtirish, ANSYS Lumerical, quyosh energetikasi, mintaqa iqtisodiyoti.

Аннотация. В статье анализируется значение тонкоплёночных солнечных элементов нового поколения на основе CIGS для региональной экономики Узбекистана. Рассмотрены структура, преимущества и последние рекордные результаты CIGS-элементов. Освещены современные тенденции компьютерного моделирования солнечных элементов и роль ANSYS Lumerical в совместном моделировании оптических, электрических и тепловых процессов. Даны рекомендации по развитию научного потенциала и подготовке кадров.

Ключевые слова: солнечный элемент CIGS, тонкая плёнка, моделирование, ANSYS Lumerical, солнечная энергетика, региональная экономика.

Abstract. Against the background of rapid solar energy growth in Uzbekistan, the paper analyses the importance of new-generation CIGS thin-film solar cells for regional economies. The structure, advantages and recent record results of CIGS cells are reviewed. Modern trends in the computer simulation of solar cells and the role of ANSYS Lumerical in the coupled modelling of optical, electrical and thermal processes are discussed. Recommendations on developing local research capacity and training specialists are given.

Keywords: CIGS solar cell, thin film, simulation, ANSYS Lumerical, solar energy, regional economy.

Introduction

Uzbekistan has become the regional leader of solar energy in Central Asia: by the end of 2025 its installed solar capacity reached about 5.9 GW, solar and wind supplied about 12% of electricity, and about 3.2 billion m³ of natural gas was saved [1]. By 2030 the country plans to have 27 GW of renewable

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capacity [2]. However, almost all installed modules are imported crystalline silicon (c-Si) panels, whose output drops in the hot and dusty climate of regions such as Khorezm and Karakalpakstan. For long-term sustainability, regions need not only new power plants, but also the scientific capacity to select, adapt and eventually produce new-generation photovoltaic technologies. Thin-film CIGS solar cells and their computer modelling are a promising direction for such work.

CIGS solar cells. $Cu(In,Ga)Se_2$ (CIGS) is a direct-gap semiconductor with a very high absorption coefficient, so an absorber only 1–3 μm thick absorbs most of the sunlight, about 100 times thinner than a silicon wafer. A typical cell has the structure glass/Mo/CIGS/CdS/i-ZnO/ZnO:Al (or ITO) (Figure 1). The bandgap can be tuned from about 1.0 to 1.7 eV by changing the Ga/(In+Ga) ratio, which allows gallium grading and makes CIGS an ideal bottom cell for tandems. In 2024 Uppsala University and First Solar reached a certified record efficiency of 23.64% using silver alloying and a steep back-contact Ga gradient [3], and in 2025 HZB reported a perovskite/CIGS tandem cell with 24.6% efficiency [4]. The main properties of CIGS in comparison with c-Si are given in Table 1.

Table 1. Comparison of CIGS and crystalline silicon solar cells

Parameter	CIGS (thin film)	c-Si (wafer)
Bandgap, eV	1.0–1.7 (tunable), direct	1.12, indirect
Absorption coefficient, cm^{-1}	~10^5	~10^2–10^4
Absorber thickness, μm	1–3	130–180
Record cell efficiency, %	23.64 [3]	≈27–28 [5]
Flexible / lightweight modules	possible	limited
Tandem application	bottom cell (24.6% [4])	bottom cell

Source: compiled by the author based on [3–5].

For Uzbekistan, CIGS is attractive for lightweight rooftop and building-integrated systems, agricultural and off-grid applications, and as a basis for future tandem modules. Its low material consumption also opens a niche for local research and small-scale production.

Modern trends in solar cell simulation. Simulation allows researchers to test hundreds of designs before expensive fabrication. Classical one-dimensional programs such as SCAPS-1D [6] remain popular for fast analysis of layer thicknesses, doping and defects. Current trends are: (1) a move to 2D/3D models that describe grain boundaries, nanotextures and contact geometry; (2) coupled multiphysics, in which optical, electrical and thermal problems are solved together; (3) simulation of tandem cells and current matching; (4) machine-learning surrogate models and inverse design that speed up optimisation by orders of magnitude [7]; (5) calibration of models against measured J–V and quantum efficiency data.

The role of ANSYS Lumerical. Lumerical provides exactly this multiphysics chain (Figure 1). The FDTD or STACK solver calculates light absorption in the real layer geometry and the spatial generation rate; CHARGE solves the drift-diffusion equations with SRH, radiative and Auger recombination and gives the J–V curve, Voc, Jsc, fill factor and efficiency; HEAT estimates the cell temperature; and the Python API and optiSLang automate parameter sweeps and optimisation [8]. For CIGS this makes it

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possible to study Ga grading, ultrathin absorbers with back reflectors, alternative Cd-free buffers and perovskite/CIGS tandems.

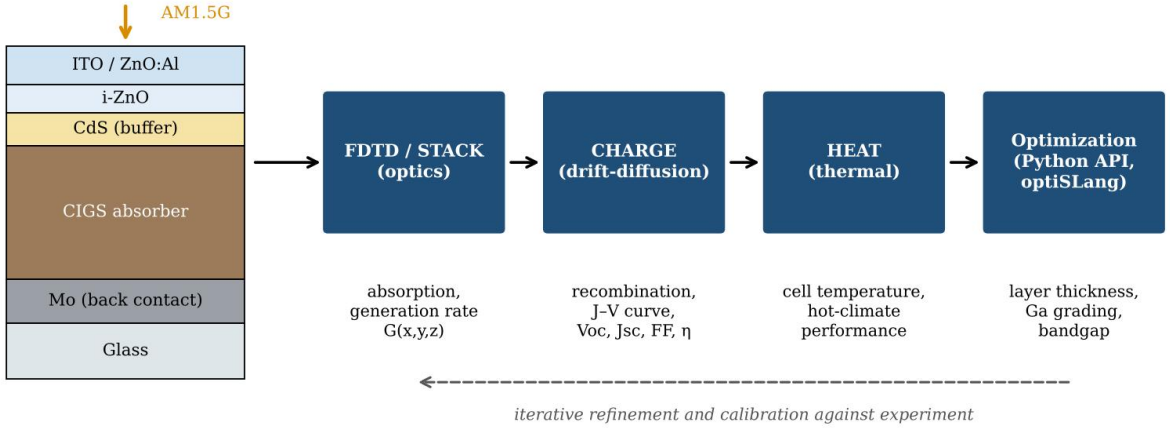


Figure 1. Structure of a CIGS solar cell and the multiphysics simulation workflow in ANSYS Lumerical

Source: prepared by the author based on [8].

Results

Our preliminary modelling of an ITO/ZnO/CdS/CIGS/Mo cell in Lumerical CHARGE showed that the open-circuit voltage is highly sensitive to carrier lifetimes, interface recombination and band alignment: with uncalibrated parameters, Voc was overestimated in comparison with typical experimental values of 0.7–0.9 V. This confirms that reliable simulation requires a validated material database and comparison with experiment. Such skills are in high demand: every percent of module efficiency gained in hot regions means more electricity from the same land, investment and grid connection, i.e. higher returns for regional solar projects.

Conclusion

CIGS thin-film cells, especially in tandem with perovskites, are among the most promising new-generation PV technologies for the hot, sunny regions of Uzbekistan. Modern multiphysics tools such as ANSYS Lumerical allow these cells to be designed and optimised at low cost. It is proposed to: (1) create joint simulation and measurement laboratories in regional universities; (2) include courses on solar cell modelling (SCAPS, Lumerical) in physics and engineering curricula; (3) test thin-film and tandem modules under local climatic conditions. This will help turn the solar boom into a source of local knowledge, jobs and sustainable regional development.

References

1. IRENA. Renewable Capacity Statistics 2026. – Abu Dhabi: IRENA, 2026; Uzbekistan doubles solar and wind power generation in 2025 // Renewables.az, 2026. – URL: https://renewables.az
2. Uzbekistan targets 27 GW renewable capacity, 40% of power generation by 2030 // Enerdata, 2024. – URL: https://www.enerdata.net

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3. Keller J. et al. High-concentration silver alloying and steep back-contact gallium grading enabling copper indium gallium selenide solar cell with 23.6% efficiency // Nature Energy. – 2024. – Vol. 9. – P. 467–478.
4. CIGS-perovskite tandem cell hits record 24.6% efficiency // PV Tech, 05.02.2025. – URL: https://pv-tech.org
5. Green M.A. et al. Solar cell efficiency tables (Version 66) // Progress in Photovoltaics. – 2025. – Vol. 33.
6. Burgelman M., Nollet P., Degrave S. Modelling polycrystalline semiconductor solar cells // Thin Solid Films. – 2000. – Vol. 361–362. – P. 527–532.
7. Singh A., Gagliardi A. Drift-diffusion modeling of perovskite solar cells: past and future possibilities // EES Solar. – 2025. – DOI: 10.1039/D5EL00040H.
8. Ansys Optics. Solar cell simulation methodology (FDTD and CHARGE). – URL: https://optics.ansys.com/hc/en-us/articles/360042165634

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