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Molybdenum slims solar panels

Imagine hiking through a remote wilderness, using a lightweight, bendable solar panel on a backpack to charge your phone. Or imagine aircraft that use sunlight to reduce reliance on fuel. The lightweight technology that makes this possible, known as a copper-indium-gallium-selenide (CIGS) thin-film, is pushing solar energy into places conventional silicon cannot reach. CIGS relies on a micrometer-thin layer of molybdenum, applied with atomic precision, that enables performance in the harshest conditions, from disaster zones to deep space.

This specialty high-altitude aircraft can hover in the stratosphere for up to a year, with CIGS solar panels and onboard batteries powering its observation and communications systems. © Sceye

The vast majority of solar panels use silicon wafers, which produce electricity when struck by visible light. Silicon modules are so popular because mass production has made them highly efficient and cost effective. However, they are also bulky, heavy, and fragile. Thin-film modules, in contrast, are up to 20 times thinner and significantly lighter. They can also be flexible, even bendable, depending on the substrate. They perform better than silicon in low light conditions, including on cloudy days, in late afternoon, or in shaded urban environments.

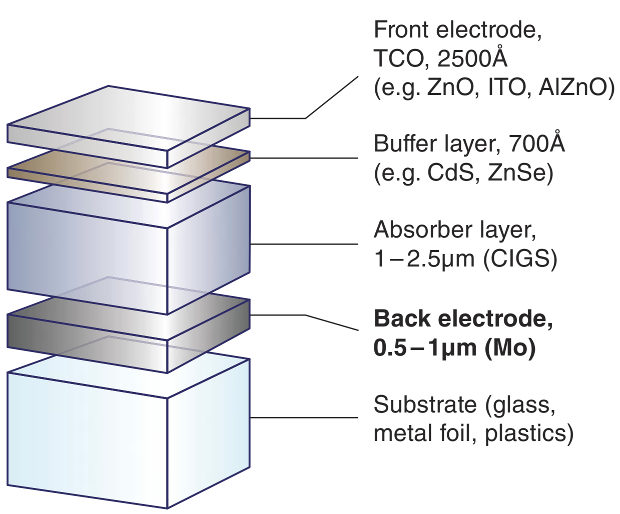
These versatile attributes open a new range of surfaces where electricity can be generated: on specialty aircraft like drones, weather balloons, and satellites, on building envelopes, even personal camping gear like tents and backpacks. For example, a solar research facility in Berlin produces over 30,000 kilowatt-hours of electricity a year – enough to power multiple homes, using CIGS panels seamlessly integrated into its façade. In disaster relief efforts, foldable solar sheets based on CIGS technology can provide essential power for lighting, communications, and refrigeration. Similarly, thin-films on car roofs help extend driving range for electric vehicles by charging while in motion. In each case, a microscopic layer of molybdenum is integral to the design.

Berlin's "living lab" features rigid CIGS panels in a customized blue color, complementing the metal cladding of the facade.

Painting with atoms of molybdenum

Molybdenum is used in the two most common types of thin-film solar cells: in CIGS and in older designs of cadmium telluride (CdTe). While CdTe cells once used molybdenum, many producers have phased it out in favor of less costly alternatives. However, in CIGS molybdenum remains virtually irreplaceable. Every solar cell needs what's called front and back electrodes, which collect and transport electricity generated in the semiconductor layer. Molybdenum serves as the back electrode in CIGS cells. Its thermal expansion closely matches that of the soda-lime glass substrate, preventing stress and cracking during the high temperature manufacturing process. Molybdenum adheres strongly to both glass and the CIGS absorber, ensuring structural integrity through thermal cycling and mechanical handling. It stays conductive and chemically stable at processing temperatures above 500°C. Additionally, a thin molybdenum-selenide ($MoSe_2$) layer naturally forms at the interface, reducing electrical resistance and boosting performance.

Example of a CIGS module structure
(Layers deposited from bottom to top)



CIGS' molybdenum layer is applied to the substrate using a technique called sputtering. During sputtering, a solid piece of molybdenum called the sputtering target is placed inside a vacuum chamber. Argon gas inside the chamber is energized to create a plasma, and charged particles from the plasma knock atoms from the molybdenum target onto the substrate. This spray-painting like process results in an uniform layer, typically 400 to 1,000 nanometers thick, which is 100 times thinner than a human hair.

Like in any coating method, evenness and efficiency are important. Traditional flat targets can wear unevenly, creating a trench-like erosion pattern in the center over time, wasting valuable molybdenum on the edges. Sometimes just 30 – 40% of the material is used before needing replacement. Using a rotating cylindrical target ensures even wear across the entire target, dramatically reducing waste by depositing up to three times more material, requiring fewer changeovers and lowering sputtering costs.

An unused rotary sputtering target in the factory. This is an example of a monolithic target made of a single material.

A flat sputtering target shows grooves of use after many production cycles. Once it is too thin, the rest of the target is recycled.

Rotary targets typically consist of a molybdenum tube bonded onto a structural stainless steel or copper backing tube for support and heat removal. However, this bonded structure adds complexity and cost and requires rare, expensive soldering materials like indium. To simplify the process, some producers offer monolithic targets: tubes made entirely of molybdenum with no backing tube or bonding layer. This design allows nearly the entire wall thickness to be sputtered, improving sustainability and cost effectiveness through more efficient material use, easier recycling, and reduced maintenance and downtime in production lines.

Flexible CIGS modules use stainless steel or plastic substrates, which unlike soda-lime glass, do not naturally release sodium, a key element that improves cell efficiency. To compensate, sodium or potassium doped molybdenum targets have been developed. This allows the beneficial alkali elements to diffuse into the CIGS layer during processing, increasing efficiency by up to 30–50%.

Beyond its role as a target material, molybdenum is also used in vacuum evaporation systems that deposit the CIGS or CdTe absorber layer at high temperatures. Its resistance to heat and harsh chemical environments makes it ideal for shields, crucibles, boats, and structural supports within these tools.

Many roofs cannot support the weight or shape of silicon panels. Lightweight CIGS modules can be easily installed, even on existing buildings.

In tests across Europe and North America, CIGS solar panels on long-distance buses delivered measurable fuel savings.

What's next?

Solar panel installations tripled between 2018 and 2023. This growth is driven in part by the expanding variety and accessibility of solar technologies. Looking ahead, CIGS could play a role in next-generation tandem solar cells that combine two materials to boost performance. One of the most promising partners is perovskite, a lightweight and potentially low cost solar material with high efficiency and simple production methods. Because CIGS and perovskite absorb different parts of the solar spectrum, stacking them allows more sunlight to be converted into electricity.

Despite economic uncertainty and global tension, energy investment is expected to reach a record $3.3 trillion in 2025, according to the International Energy Agency's (IEA). About two-thirds of this, roughly $2.2 trillion, will go to low carbon technologies including renewables, nuclear, storage, energy efficiency, and electrification. Solar leads the way, with investment in rooftop and utility-scale systems projected to reach $450 billion.

Thin-film solar modules currently make up less than 3% of the global solar market. While this share is small, demand is rising as the overall solar industry expands. Instead of silicon, CIGS is claiming a durable niche in specialty applications where weight, flexibility, or aesthetics matter most. Wherever these applications appear, on walls, in orbit, or in the wilderness, a micrometer-thin layer of molybdenum will likely be working behind the scenes. (Karlee Williston, Nicole Kinsman)

Thanks to Christian Linke and Thomas Huber of Plansee for their technical interview, which provided the basis of this article and to Valter Pakdeerat of Midsummer for his valuable input.

CIGS panels can be made flexible, scratch-proof, and waterproof for nature excursions and extreme sports.