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Getting Moore from Solar Cells

David J. Norris and Eray S. Aydil

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ncRNAs across the yeast genome. Furthermore, by focusing on pairs of tandem genes where the promoter of the downstream gene is far from the termination region of the upstream gene, the authors established that enhanced synthesis of ncRNAs originates from the downstream bidirectional promoter, rather than from the upstream polyadenylation site (see the figure). Enhanced expression of CUTs, previously detected in the Δ*rrp6* deletion mutant, as well as an extensive set of new CUTs called SRTs (Ssu72-restricted transcripts), were observed in the *ssu72-2* mutant. However, enhanced synthesis of these ncRNAs was not specific to the *ssu72-2* mutation; other mutations that block looping—including *sua7-1* (which encodes a mutated form of TFIIB) and defects in the Pta1, Rna14, and Rna15 components of the 3′-end pre-mRNA processing machinery—exhibited similar enhancement of CUTs and SRTs. Accordingly, Tan-Wong *et al*. define a new function for gene loops: repression of ncRNA synthesis from bidirectional promoters.

It remains to be determined how gene loops repress upstream transcription. One scenario is that bidirectional transcription is mutually exclusive: Formation of one initiation complex precludes formation of an adjacent complex of opposite polarity. In this case, a promoter-terminator loop would simply repress ncRNA transcription by default. This possibility is consistent with the small decrease in mRNA production associated with the *ssu72-2* mutant observed by Tan-Wong *et al*. Alternatively, gene loops might actively block ncRNA synthesis, perhaps by localized recruitment of a repressive histone deacetylase complex.

Gene loops are not unique to yeast. For example, the HIV provirus forms a transcription-dependent gene loop between the 5′ long terminal repeat (LTR) promoter and the 3′ LTR polyadenylation site (*14*). Interestingly, proper 3′-end formation of mammalian β-globin mRNA stimulates transcription initiation of the β-globin gene —an effect that is most easily explained by looping-mediated recycling of Pol II (*15*). The extent to which gene loops might be a general feature of Pol II transcription awaits further investigation.

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MATERIALS SCIENCE

Getting Moore from Solar Cells

Exploring alternative device designs and component materials will be crucial in improving solar cell performance.

David J. Norris[1] and Eray S. Aydil[2]

Biological organisms, when faced with a difficult environment, take advantage of the process of mutation. Beneficial mutations can help to optimize a known survival strategy or even reveal a new one. In solar cell research, a similar process is occurring. Solar cells must continue to improve in efficiency and cost if they are to thrive as a viable energy technology. Through the implementation of variations on known device architectures, "mutant" solar cells are leading not only to important incremental improvements but also to surprising new approaches. On page 643 of this issue, Lee *et al*. (*1*) demonstrate an example of the latter, introducing a new species of solar cell for study.

Photovoltaic solar cells convert sunlight into usable electrical power. After decades of research, several device archetypes have been established. These include long-standing approaches, such as the common silicon solar cell (*2*, *3*), and newer alternatives at various stages in their development (*4*). One example is the dye-sensitized solar cell (*5*), first reported in 1991. Unlike the silicon cell, it is a hybrid device made of both inorganic and organic components. A porous film of inorganic titania particles is deposited on an electrode. When a single layer of an organic dye molecule decorates the surface of these particles, sunlight is absorbed by the dye, generating electrons. If extremely small (nanometer-scale) titania particles are used, even a thin film contains sufficient surface area that most of the sunlight is absorbed by the dye. A voltage can then be established between the titania-coated electrode and a counterelectrode when a liquid electrolyte is placed in between. In this configuration, the device produces power when the film of titania particles performs several functions simultaneously: It provides a scaffold for the dye, collects the generated electrons, and transports these charges to the electrode.

Initially, dye-sensitized solar cells converted full sunlight into electricity with an efficiency of 7.1% (5). By comparison, crystalline silicon solar cells convert full sunlight into electricity with an efficiency of 25%. However, because titania particles are inexpensive to produce and spread on a surface, dye-sensitized solar cells were pursued as a low-cost alternative to silicon. Moreover, through optimization of the dye and the electrolyte, their efficiency now stands at an impressive 12.3% (6).

The basic concept of the dye-sensitized solar cell has also provided a good launching point for "mutations" to further improve this performance. The titania nanoparticles have been replaced with other structures, such as semiconductor nanowires (*7*, *8*); the dye replaced with other light absorbers, such as semiconductor quantum dots (*9*); and the liquid electrolyte replaced with solid conductors, such as organic semiconductors (*10*). Changing two of these simultaneously has also been explored (*11*). However, so far, none of these mutations have yielded cost or efficiency benefits over the conventional dye-sensitized solar cell.

By changing three elements of the dye-sensitized solar cell simultaneously, the results reported by Lee *et al*. suggest a shift in that stalemate. They replaced the titania

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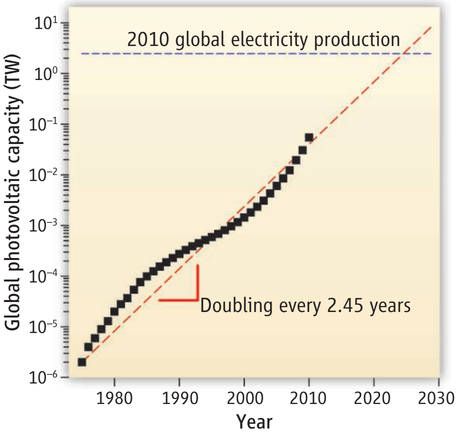

Moore's law for solar cells. The accumulated amount of photovoltaic solar cells manufactured from 1975 to 2010, in terawatts (*13*). The red dashed line is a linear fit to the data and represents a doubling of the global capacity every 2.45 years since 1975. The blue dashed line is the gross electricity produced globally from all sources in 2010 (*14*) for comparison.

nanoparticles with alumina nanoparticles, the dye with a thin layer of an organic-inorganic perovskite (*12*), and the liquid electrolyte with a solid organic conductor. The outcome was a device that converted full sunlight with an efficiency of 10.9%, a truly impressive number, especially for a combination one might not expect to perform at all.

In particular, alumina is nonconductive and cannot transport the light-generated electrons to the electrode. Consequently, the alumina performs only one of the three required functions—a high-surface-area scaffold upon which the light-absorbing perovskite is placed. But then how does the device work? The other functions are apparently assumed by the perovskite, which is a hybrid solid consisting of an inorganic framework (a metal halide) with small organic molecules in its voids. Although this sounds exotic, these materials are known to behave like semiconductors, allowing them to absorb the sunlight and create electrons. Without the titania, the perovskite also has to transport this charge to the electrode. Because the overall device performance is high, the perovskite apparently accomplishes all of these tasks surprisingly well.

Replacing the simple organic dye with the perovskite also sounds complicated (and expensive). However, Lee *et al.* show that highly crystalline layers of these materials can be grown simply by coating the surfaces of the alumina particles with a solution of low-cost molecular precursors followed by mild heating. The high structural quality of the resulting films is presumably one reason the perovskite can collect and transport the electrons so efficiently. Because the absorbing layer is produced by simple and inexpensive solution processing, the Lee *et al.* device also maintains a primary advantage of the conventional dye-sensitized solar cell: low cost.

On the basis of this first report, researchers can now evolve the new device and search for further improvements. An obvious target is the organic-inorganic perovskite. The specific lead halide used is only one example of a large class of possible perovskites (*12*). Exploring related materials can also provide an opportunity to eliminate the lead, a worthwhile goal for environmental protection.

These and other "mutants" are intended to help photovoltaic solar cells make an impact on the world's electricity production (see the figure). Global photovoltaic solar cell capacity has doubled every 2.5 years between 1975 and 2010. Such exponential growth is reminiscent of the famous Moore's law in integrated circuits, which states that the number of transistors on a computer chip doubles every 2 years. Although not a physical law, it has provided a self-fulfilling prophecy for the computer industry for several decades. Will solar cell manufacturers be able to maintain their Moore-like growth? In particular, recent increases have occurred during a period of government subsidies. If the political or economic environment changes, then technological improvements in performance and cost will be needed more than ever to stay on track. Research on mutant solar cells, which can lead to improvements in both efficiency and cost, has an important role to play in achieving this goal.

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BIOCHEMISTRY

Templating a Molecular Tug-of-War

Michael R. Diehl

Tying cytoskeletal motors together on a DNA rope reveals how opposing motors compete to determine the direction of cargo transport.

The activated transport of organelles, vesicles, and many other subcellular commodities along cytoskeletal filaments is central to mechanisms that regulate the internal organization of eukaryotic cells (*1*). The motions of these cargos are driven by several classes of ATP–dependent enzymes called motor proteins that are capable of converting chemical energy into mechanical work. A variety of bulk biochemical and single-molecule techniques have been developed over the past decade to characterize the principles that allow these enzymes to function effectively as molecular machines (*2*, *3*). Yet most cargos are transported by multicomponent motor systems containing multiple copies of the same motor, or even by mixtures of different classes of motors that move with different velocities, in opposite directions, and along different types of cytoskeletal filaments (*4*, *5*). Understanding how motors cooperate productively and compete antagonistically has therefore become increasingly important for dissecting mechanisms that regulate intracellular transport as well as the impact of motor mutations in diseases. On page 662 of this issue, Derr *et al.* (*6*) demonstrate a new materials approach to these problems that allows the characterization of key relationships among the structural organization of multiple motor systems, the

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