Electronic Design

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Pushing the Power Density in Outer Space Systems

Power density is vital for autonomous, remotely operated, or manned systems in outer space.

Generating electricity at nighttime using renewable resources has become extremely important since a billion people on Earth are living off some electric grid. With no solar power at night, users may instead employ the coldness of the universe as a thermodynamic resource.

Specifically, users will be able to use a heat engine that can extract energy using the temperature gradient between the ambient environment maintained close to 300 K and outer space steady at approximately 3 K. Such a method will enable efficient dumping of excessive heat from the heat engine output through a stable low-temperature cold sink, namely outer space.

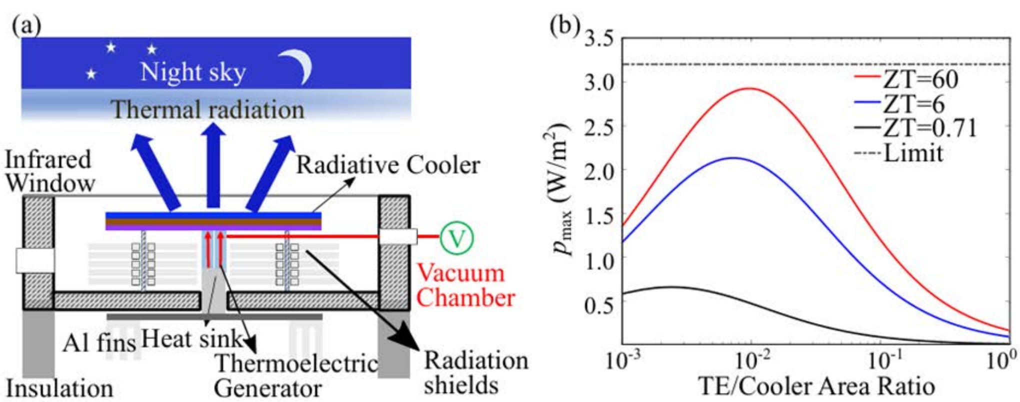
On this front, the first article in the References listed below presents an efficient optimization of a nighttime thermoelectric power generation system using radiative cooling. The authors demonstrate an electrical power density greater than 2 W/m^2—it's two orders of magnitude higher than previous works and is achievable using existing technology.

Even though this demonstration of nighttime electrical power generation is amazing, the confirmed power density is quite low. Achieving a power density at a 1 W/m^2 level is key to fulfilling the energy demand of innumerable applications.

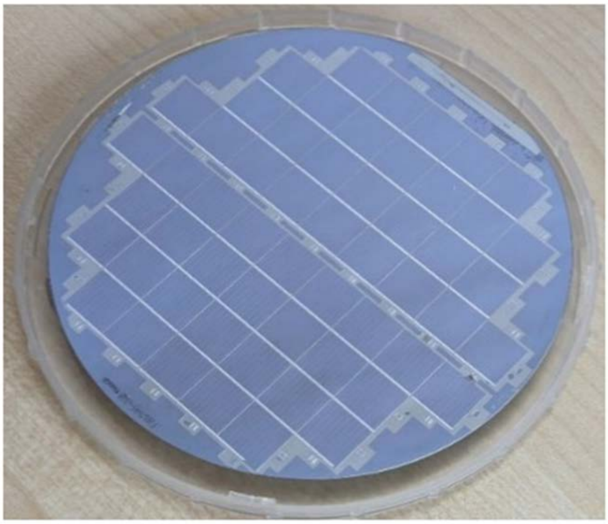
Designers can improve power generation by taking on these two challenges:

1. The emitter simply needs to absorb heat power at frequencies/angles where the atmospheric emission is low, while a simple blackbody emitter[2] absorbs heat power strongly at all frequencies and angles.
2. The thermal design should mitigate the excessive parasitic heat loss that's detrimental to forming thermoelectric current.[2]

The proposed system *(Fig. 1)* allows for optimal power generation at nighttime. It combines radiative cooling and thermoelectric power generation and can operate at night when solar energy harvesting isn't available. The system



1. The system proposed allows for optimal power generation at nighttime: (a) Schematic of the setup. (b) The output power density p_{max} is a function of a thermoelectric-to-radiative cooler area ratio for various thermoelectric figure-of-merit values, including the limit determined by half of the Carnot engine extracted power density. Here, $h_c = 10^{-3}$ W/(m^{2}K) and $h_h = 10^2$ W/(m^{2}K) at the ambient temperature of 300 K. (Image courtesy of Reference 1)



2. This 100-mm epiwafer incorporates 1-cm^2 gallium-indium-phosphide (GaInP)/gallium-indium-arsenide (GaInAs)/germanium (Ge) lattice-matched (LM) triple-junction (3J) solar cells. (Image courtesy of Reference 3)

delivers a power density of more than 2 W/m^2. That's two orders of magnitude higher than any previously reported experimental result achieved using existing technologies.

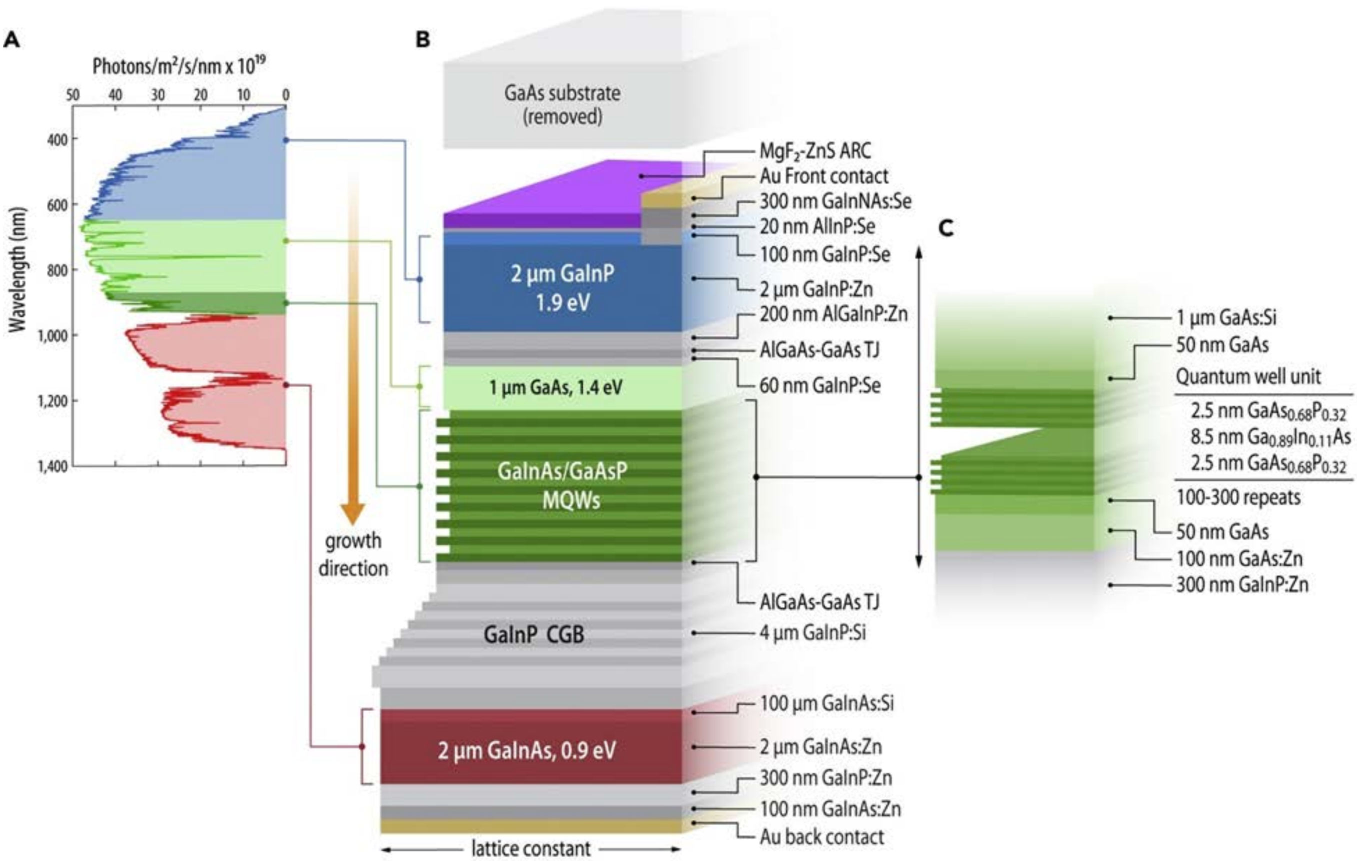
The thermoelectric power generator (TEG) occupies less than 1% of the system area footprint when achieving optimal power generation. The importance of the optimal emitter becomes clear with the gain of 153% in power density as compared to regular blackbody emitters.

Space Applications Under Development

It's important to examine the quality of the whole manufacturing process in a significant number of devices—tens of 1-cm^2 solar cells are defined by photolithography and tested *(Fig. 2)*. Larger cell sizes, relevant to space applications, are under development.

For instance, there's the triple-junction inverted metamorphic multijunction (IMM) structure, which includes quantum wells (QWs) in the middle sub cell. In *Figure 3*, layer thicknesses are shown for the global device, while the space device is slightly modified.

Another application—the electrical power system (EPS) in spacecraft—provides electrical power to all vehicle loads and is vital for the safe completion of NASA-defined mis-



3. Shown is a triple-junction solar cell. (Image courtesy of Reference 5)

sions. The EPS encompasses electrical power generation, distribution, and storage. The EPS is also a major fundamental subsystem and comprises a large portion of volume and mass in any kind of spacecraft.

When it comes to CubeSats, for example, the most commonly used architectures are battery-only or solar array/battery configurations. In these cases, batteries must be treated as potential hazards, because they sometimes combine stored energy with their caustic materials in the spacecraft.

Summary

High power density, in outer space systems, enhances many types of space-related applications. Spacecraft must rely on robust power systems to handle the challenges of deep space missions. Thus, reliable power-management and storage technologies are crucial for any mission success.

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