Laser Power Beaming for Lunar Polar Exploration
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The poles of the moon have permanently shadowed craters that are known to hold frozen volatiles such as water ice.

- These are of great interest for both science and for resource utilization
- Identified as a high priority targets for future NASA exploration.
- South pole region is baseline landing site for NASA Artemis human exploration

But electrical power is a challenge for design of rovers for lunar polar operations.

- The interior of polar craters, with a complete absence of sunlight, means conventional solar power systems cannot operate.
- This has been identified as a significant technology challenge for NASA’s future exploration.

Power beaming has been proposed using both laser and microwave sources.

- Wavelength for optical beaming is factor of ~10^4 shorter than microwaves. Thus optics are smaller, and hence systems are much more compact.
- On the other hand, generation of microwaves can have efficiencies of 85% or higher, while the best lasers have ~50% electrical-to-light efficiency
- Both systems have possible applications in space

A possible advantage of laser power receivers is that a photovoltaic panel to convert laser radiation will also convert sunlight. When rover moves into an illuminated area, a laser receiver functions as a solar array.

For laser power beaming, the laser choice is required to optimize the following criteria:

- Laser has high electrical to optical conversion efficiency
- Cell has high optical to electrical conversion efficiency
- (requires laser wavelength selected to match the cell choice)
- High power possible
- High beam quality

Laser choice: Beam Quality

- Low coherence light sources project can focus to a spot size based on classical object/image optics
  • (but not less than diffraction limit)
- High coherence light sources can project a spot size as small as the diffraction limit

Two types of laser have the required high efficiency

- Diode laser bars have low coherence
  • Essentially a classical light source: light output is not in phase
- Diode-pumped lasers have high coherence
  • Light output is in phase

Diode laser bars are available with short wavelengths, with low coherence.

Photovoltaic receiver choice

For maximum conversion efficiency, the cell needs energy bandgap slightly lower than the photon energy

E = hν/λ

- For bandgap less than this, efficiency drops proportional to wavelength
- For bandgap higher than this, efficiency is zero
- either select a photovoltaic cell to match the laser, or select laser wavelength to match the cell choice.

Laser choice: 810 nm
Commercial semiconductor diode laser bars are available with electrical-to-optical efficiency over 55% at 810 nm, at power >1 kW.
Wavelength can be selected for a range of visible and near-IR.

Laser choice: 1060 nm
Diode-pumped fiber lasers available commercially have realized efficiencies of up to 50% at a wavelength of about 1.06 µ.

Laser receiver: 810 nm
- GaAs solar cells operating at 810 nm have the highest reported efficiency for converting laser illumination to electricity
- Well-developed technology, flown in space
- Efficiency of up to 60% has been reported*
  • but this is for fiber transmission, not free-space
- receivers with efficiency of 53% at λ=810 nm are Commercially available.

Laser receiver: 1060 nm
- Two reasonable cell choices.
  1. III-V ternary or quaternary alloy at a bandgap selected to match the laser, about 1.08 eV.
- Reported efficiency for 1 cm² cells range from
  • 31.5% to 37.87% at 538 mW/cm² incident power density at 1064 nm
- Not a commercially available product

2. Silicon cells.
- Despite bandgap near optimum, Si has a low absorption constant at 1064 nm
- hence conventional silicon cells have poor spectral response at this wavelength.
- Advances in Si solar cell technology have pushed long wavelength response

Laser choice: 1060 nm (but not less than diffraction limit)
λc is the diameter of transmitter lens , F is the focal length of the receiving lens, D is the diameter of the receiving aperture.
Diode-pumped fiber lasers available commercially have realized efficiencies of up to 50% at a wavelength of about 1.06 µ.

Laser: Beam Quality

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Trade-off choices: available technology

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