

P1_8 Ice Ice, Maybe

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Abstract

Many types of water ice can have semiconducting properties, particularly when doped, due to their crystalline structure. These properties may possibly lend the material to being used to create photovoltaic cells on distant planetary bodies. A band gap of 7.8 eV for cubic ice and 5.15 eV for ice XI give a reviewed solar spectral radiance of $1.51 \times 10^{-11} \text{ W sr}^{-1} \text{ m}^{-2} \text{ Hz}^{-1}$ and $9.45 \times 10^{-10} \text{ W sr}^{-1} \text{ m}^{-2} \text{ Hz}^{-1}$ respectively. This gives a very low amount of useful radiation at Europa and an even smaller amount 67P/Churyumov–Gerasimenko, bringing extreme doubt on the use of this novel method.

Introduction

There is currently a large interest in aspects of space exploration such as comet mining and exploration of Jovian moons, not only in the scientific community but also in the eyes of the public. However, the tasks mentioned are no small feat and are subject to many issues which may not be as intuitive to solve as they might seem. One such issue is that of power. More specifically, maintaining a supply of power with a large lifetime. The most intuitive solution to this problem is to include a series of photovoltaic cells and batteries on any lander or vehicle. However, these cells and batteries have mass. Mass which must be taken all the way from the surface of the Earth to a comet or moon, this require monumental amounts of energy and therefore fuel to move even the smallest mass, and as more fuel is required, even more fuel is needed to lift the mass of this fuel et cetera.

Photovoltaic cells can be built using a semiconducting material. When light of energy equal to that of the material band gap, charge carries are transferred from one band to the other, when connected to a load, this drives a current. Theoretically, if there was some source of semiconducting material on these comets and moons, a photovoltaic cell could be built on site and remove much of the mass needed to transport them. Fortunately, ice is abundant through comets and several moons of interest and ice also has a crystal structure. Rocky bodies also contain other elements and compounds that could be used to dope the ice and create a p or n type semiconductor. This paper goes on to investigate the possibility of using ice as a semiconductor in photovoltaic cells on comets and in other novel examples. However this will not include a comprehensive view of the physics of photovoltaic cells to calculate a power output or necessary area as that is beyond the scale of this paper.

Theory

The band gap of a semiconductor determines which photon energies, and therefore wavelengths, can be absorbed and ultimately translate to a current generation. This relationship is elementary and can be seen as follows:

$$E_G = \frac{hc}{\lambda} \quad \{1\}$$

However, since ice is generally not a direct semiconductor, an assumption needs to be made to determine that all absorbable light incident on the cell is absorbed. It will be assumed that the cell is sufficiently thick such that no light passes through it. The Hartree-Fock prediction for the band gap of cubic ice (which is a variant of ice that exists between temperatures of 130 and 220K) [1] is 7.8 eV [2], which using {1} gives a minimum wavelength of 159 nm, and the band gap of ice XI (which exists

below 130K) is 5.15 eV, which gives a wavelength of 241 nm. Ice XI is also a direct semiconductor so the above assumption does not need to be applied and a thinner, larger area photovoltaic cell would be applicable [3].

These wavelengths are also given off by the Sun, which is assumed to radiate as a black body. We can calculate how much light is radiated at these wavelengths and is therefore useable by looking at Planck's law for blackbody radiation

$$B_{\nu} = \frac{2h\nu^3}{c^2} \frac{1}{e^{\frac{h\nu}{k_B T}} - 1} \quad \{2\}$$

where symbols hold their usual meanings and the surface temperature of the Sun is 5778K. This gives a spectral radiance of $1.51 \times 10^{-11} \text{ W sr}^{-1} \text{ m}^{-2} \text{ Hz}^{-1}$ at 159 nm and $9.45 \times 10^{-10} \text{ W sr}^{-1} \text{ m}^{-2} \text{ Hz}^{-1}$ at 241 nm.

Discussion

These values of spectral radiance are incredibly small when compared to the values for which conventional photovoltaic cells work within. This is because the wavelengths in question are in the far and mid ultraviolet, however the Sun is very large, and so even given such a small value will emit large amounts of radiation. The amount of this radiation useful to the solar cell depends on how far away from the Sun it is. This is dependent on the body on which the solar cell is being produced. For example, comet 67P/Churyumov–Gerasimenko is approximately 1.2 AU from the Sun at perihelion and is 4.1 km at its widest point. If we assume the comet to be a sphere of 2km radius (it clearly is not but this assumption will suffice) and it is known that the minimum surface temperature is 205K (cubic ice), the amount of 159 nm radiation incident at the comet can be calculated to be $3.5 \times 10^{-5} \text{ W Hz}^{-1}$. This amount is very small and puts forward the claim that, for something on the scale of 67P/Churyumov–Gerasimenko, there is only an incredibly small amount of useful solar radiation. However the moon Europa is considered to maintain an icy surface which exists at a mean surface temperature of 102 K (ice XI). The amount of useful radiation incident at Europa can be calculated to be 0.32 W Hz^{-1} , which is clearly much larger than the amount for cubic ice at Churyumov–Gerasimenko.

Conclusion

While there is a larger amount of useful radiation at Europa, this is for the size of the entire moon and it is clearly unreasonable to build a solar cell of this size, it is clear that it would be more energy efficient to simply take premade solar cells on such a mission. This leads to the conclusion that using a purely ice semiconductor photovoltaic cell is unreasonable and unrealistic, but does serve as an interesting novel idea nonetheless.

References

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