PROJECT 1C

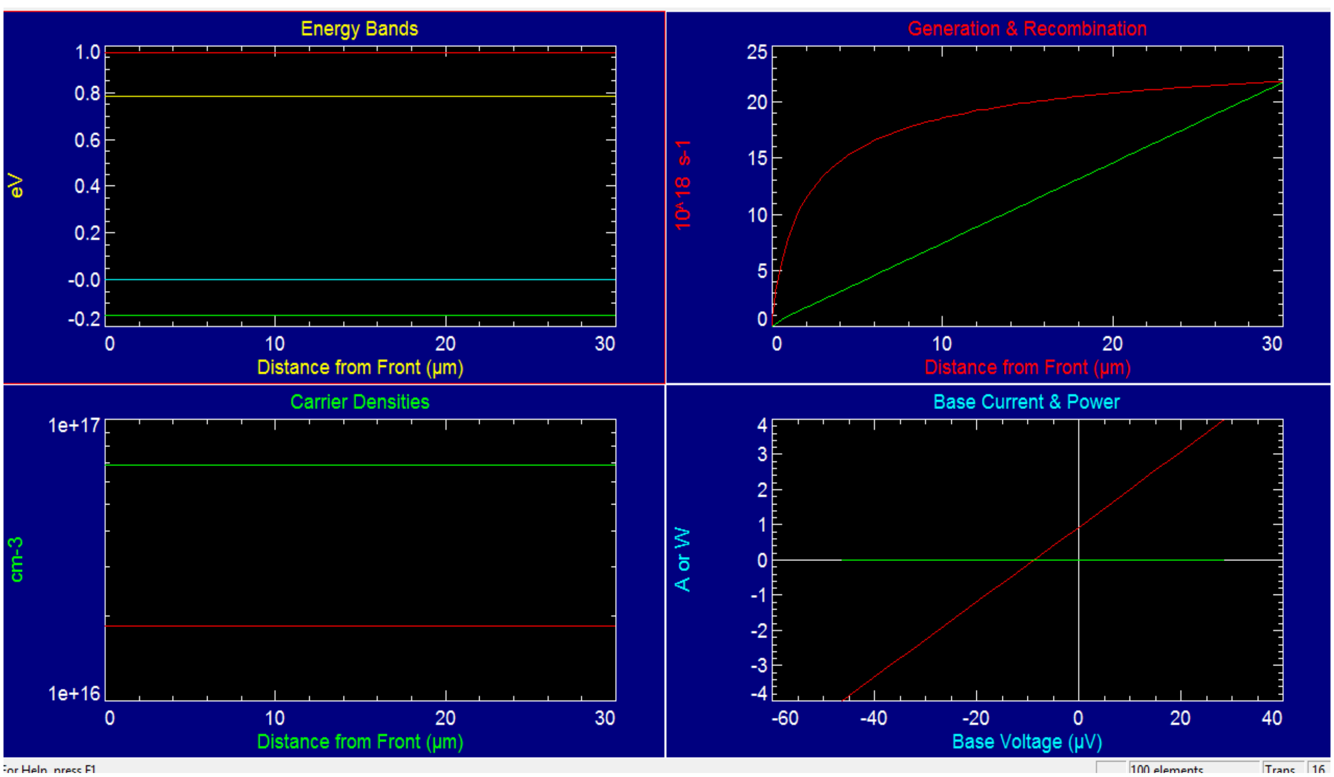
In order to maximize the max base power output *using only rational constraints*: 0.1W/cm^2, the intensity you would see from a one-sun system, enabled in the PC1D program, it was necessary to try various combinations.

The first one I tried includes the following realistic constraints imposed upon the system. My technique for determining the best system is to vary the inputs and maximize the base power output.

Properties:
Main Material: Silicon Wafer
Thickness: 30 micrometers
Surface Area: 100 square centimeters
Surface Texture: 3 micrometers
P-Doping Carrier Density: 5x10^16

RESULTS

Short-circuit Ib: 0.9442 amps
Max base power out: 2.09e-6 watts
Open-circuit Vb: -8.853e-6 volts



This combination yields a max base power output of 2.09x10^-6 watts. We can analyze the integral of the IV curve in the fourth graph (bottom right) and compare it to the size of other combinations we try. Here we get about (10microVolts)(1Amp).

Having a surface texture which is 10% of the overall thickness of the cell was a reasonable decision for the cell because 3 micrometers are enough to see results:

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RESULTS

Short-circuit Ib: 0.8912 amps

Max base power out: 1.881e-6 watts

Open-circuit Vb: -8.443e-6 volts

It is clear that the max base power out has increased—it is only 1.881x10^-6 with NO surface texture, but it is not so large as to affect the function too much—see this result with a surface texture of 25 micrometers:

RESULTS

Short-circuit Ib: 0.7695 amps

Max base power out: 1.322e-6 watts

Open-circuit Vb: -6.871e-6 volts

It has dropped to 1.322x10^-6 from 2.09x10^6 watts. In addition, it would be difficult to machine it if it were much thicker than 10% of the total thickness.

In class, we tested various carrier densities and found that 5x10^16 was the optimal choice, and will thus stick to that evidence.

It is even more important to make a final engineering decision on the *material choice.* The best way to go about this is to use PC1D to simulate various materials choices in order to see how they affect the functioning of the solar cell. In addition, it is important to consider details which PC1D cannot tell us, including cost, safety, and availability of materials. By weighing all these considerations I will present a decision at the end of this paper.

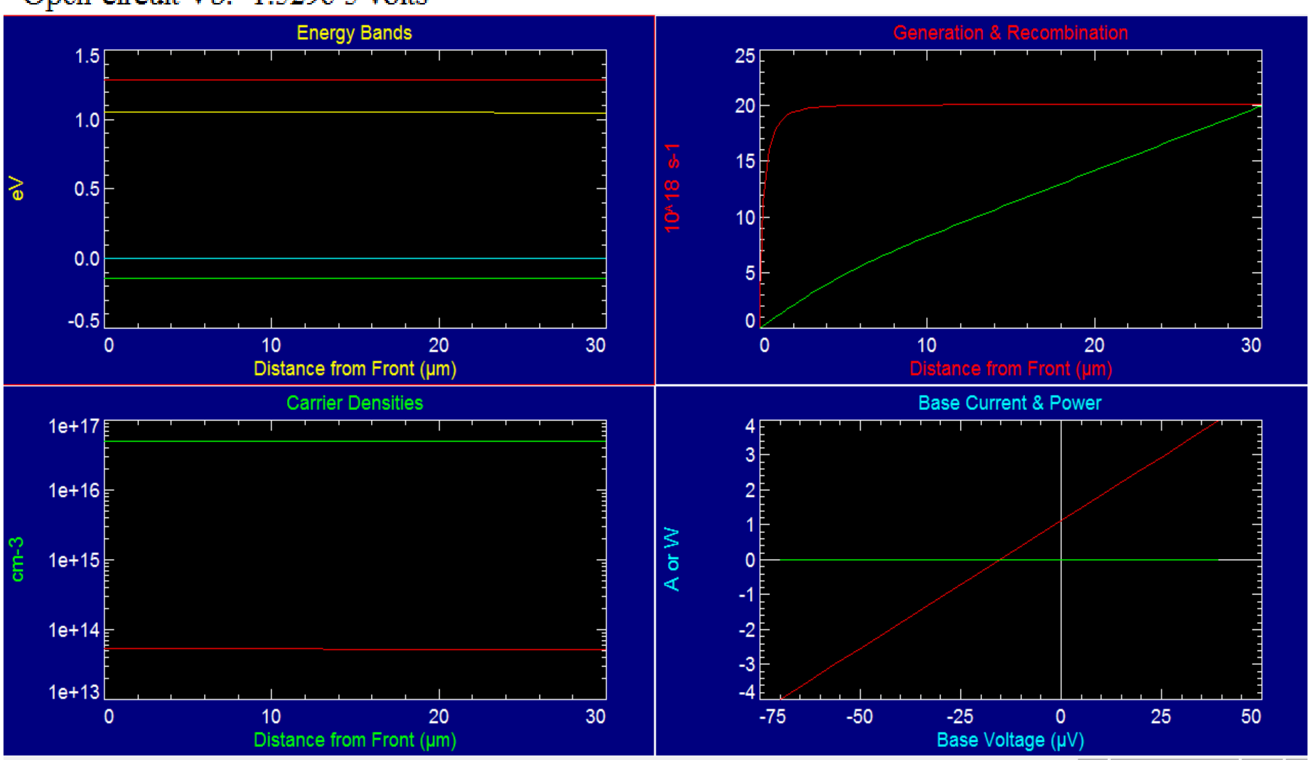
The second material we will consider is Gallium-Arsenide.

RESULTS

Short-circuit Ib: 1.119 amps

Max base power out: 4.278e-6 watts

Open-circuit Vb: -1.529e-5 volts



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From both the max base power output of 4.278x10^-6 to the integral of the IV curve--(15microVolts)(1.2Amps) it is clear that this cell can produce a better output than a silicon cell. However, there are many other factors to consider before jumping to conclusions based on this data. There are four considerations I choose to discuss here: cost, safety, availability, and usability (compatibility with current infrastructure).

Gallium does not exist freely in nature—it is rare and exists in about 17 parts per million in the Earth's crust. Arsenic is a poisonous element which if unsafely handled can be severely toxic to humans and other life forms. Both gallium and arsenic are far more expensive than silicon. Though Ga-As cells can be made thinner than Si wafers (NOT thin film, which will be discussed below), they are more expensive in the long run because of the scarcity of materials. Usability also needs to be considered—though Gallium is used widely in the semiconductor industry, infrastructure to use it for building solar cells is not common, especially not as common as that for silicon.

The next possibility to consider is thin film silicon versus wafer silicon. Leaving similar parameters that we used for thick silicon leads to reduced power output—in fact, by a factor of an entire order of magnitude!!

> **RESULTS**
> Short-circuit Ib: 0.3786 amps
> Max base power out: 1.48e-7 watts
> Open-circuit Vb: -1.563e-6 volts

However, it is important to consider that the setup and parameters described in the PC1D simulator do not match a thin film solar cell exactly—as they are set up for a silicon wafer. Thus, we need to consider data for other sources to completely understand thin film solar cells. Thin film solar cells are slightly less efficient than crystalline wafers, though they cost less. However, new technologies using the concept of having light move across the film several times to use as much energy as possible—in fact, the efficiency can reach up to 20%. There is currently much research in China geared towards understanding thin film solar cells, and this push forward could cause sweeping improvements in thin film technology.

According to (http://www.solarbuzz.com/technologies.htm), thin film solar cells currently have 18-20% of market share. Thin film has many methods to protect from degradation, including lamination processes, since degradation is one of the main concerns for thin film amorphous silicon solar cells. Thin film solar cells are cheap, and *in practice (not just theory)* maintain efficiencies CONSTANT at around 10%. Thin film is best for local power generation as it is not as hardy as possibly necessary for large scale grid generation.

Even with the PC1D simulator, with thin film silicon, we can change the doping concentration (1x10^-6) and make the silicon a combination of thin film silicon and bulk silicon—creating the following results: (with 10% surface texture)

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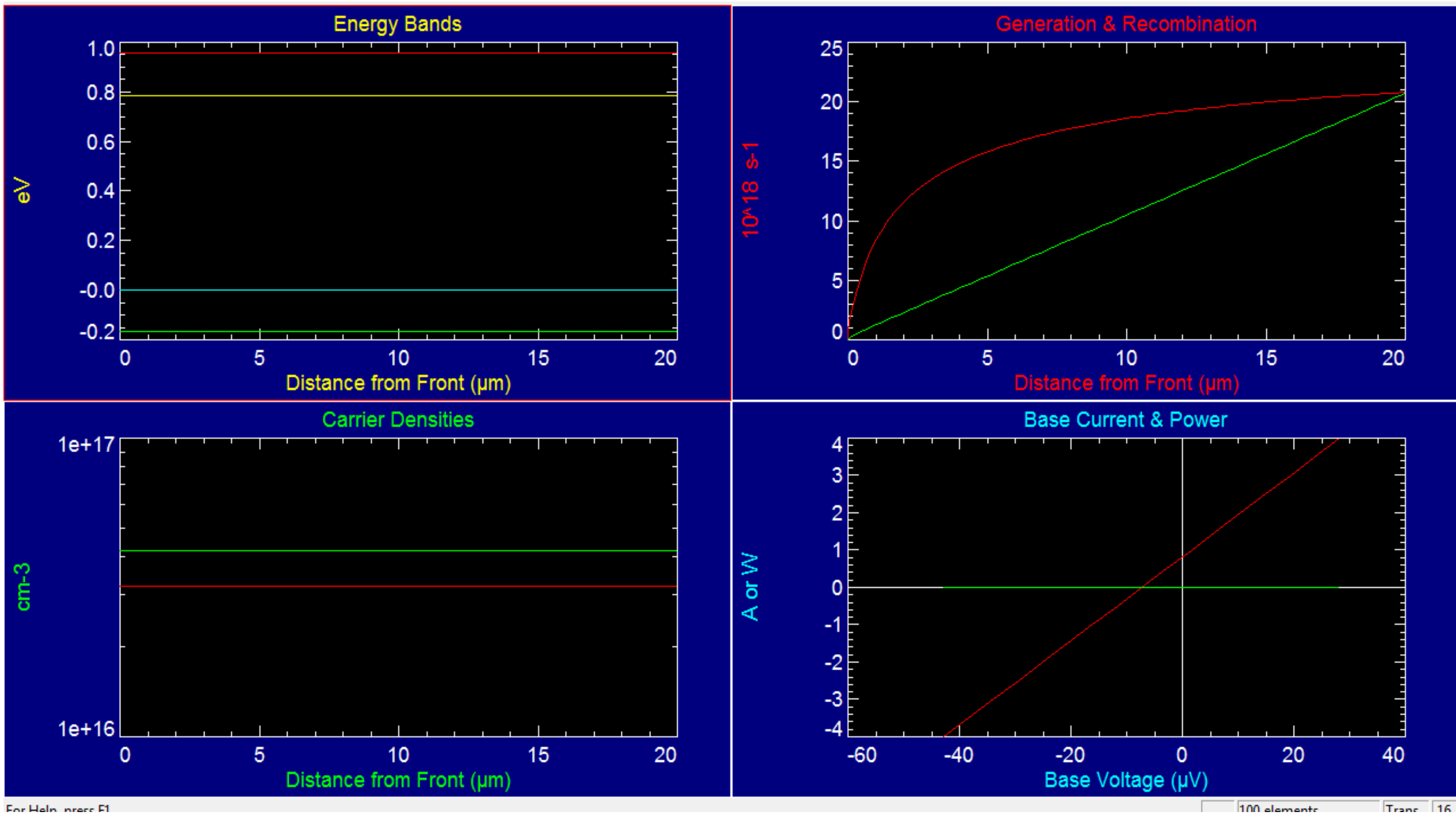
RESULTS

Short-circuit Ib: 0.8233 amps

Max base power out: 1.503e-6 watts

Open-circuit Vb: -7.301e-6 volts



This has better results than the original thin film silicon in the simulator. The simulator does not account for possible changes in local dust amounts; haze caused by dust can affect the functioning of solar cells. In addition, the simulator needs to account for various other solar cell types—so we cannot use it to evaluate them.

Conclusion

From the analysis above it is clear that thin film silicon is the most promising choice of material for the future. It is consistently efficient enough and has a low cost.

From our previous research, we have concluded that an antireflection coating of silicon nitride must be used to maximize functionality. Not only does it have a great matchup index of refraction for silicon (its index of refraction is 1.98 while silicon's is 4), but it also replaced TiO_2 because of its better functionality and availability. Silicon nitride is easy to machine onto solar cells.

Finally, silicon is perfect for our needs—it is abundant, it is cheap, it is non-toxic, and from the graphs shown above, it works the best!

PROJECT 1C

Consistency of manufacturing platform with constraints:

We decided that our solar technology implementation plan would require many solar cell factories to be built, and that we would build them gradually over a span of 20 years to allow for advances in manufacturing technology between the construction of one factory and the next, and to allow more and more people to “jump on the bandwagon” and support our ideas as we get into the later stages of our project. The gradual implementation of our ideas will allow us to, little by little, bring together a team of engineers and laborers that believe in the project. As we manufacture the solar cells, we have to make sure that we have backwards compatibility. Homeowners must be able to take advantage of our new technologies, but they must also be able to rely on the current electrical power generation infrastructure. One large constraint in this category is the fact that solar cells generate DC current, but most appliances in our houses run on AC current. During the 20 years in which we plan to implement our project, we would also plan to manufacture appliances that can run on DC current (in addition to funding research to try to convert DC current to AC current). However, some appliances, such as televisions, refrigerators, and washing machines, need to run on AC current, so they would have to use the current electrical energy infrastructure until we found a way to convert DC to AC. We would also have to keep in mind that we’d have to manufacture these cells at a cost lower than the cost of ownership, defined as (capital cost + operation cost)/(throughput * utilization * yield), because otherwise, the public would choose not to invest in them. Though solar panels have a near-zero operation cost (they only cost money if they stop working), this might be difficult because currently one solar panel can cost about $900, or $12 per watt, and a full-sized solar panel system to power a whole house can cost about $50,000, which is likely more than a homeowner would be willing to pay. This is where government subsidies should come in; we need the government to accept this technology so that we can get the public to accept it as well. We must also consider which processes will be handled by humans vs. which will be automated. We plan for most of the actual solar cell manufacturing process to be done by machines, with the installation of solar panels to be done by professionals. This will create jobs in the emerging industry without relying completely on human labor, which is the way we want it because the chances of human error are much higher than those of machine error.

As we begin to implement our solar energy plan, we will have to rely on today’s dominant energy sources. In particular, when we make our first solar cell factories, they will have to run on coal because there is no feasible way for us to make them solar powered to begin with. However, as we go further into the project, we will have enough solar cells to make new, solar-powered factories, and eventually we should be able to rework our original factories to run on solar power as well. Eventually, we hope to make our solar cells using no fossil fuels.

Based upon this analysis, a valid figure of merit is how many watt-hours our solar cells produce per pound of carbon per year. This figure of merit should follow the trend shown below:

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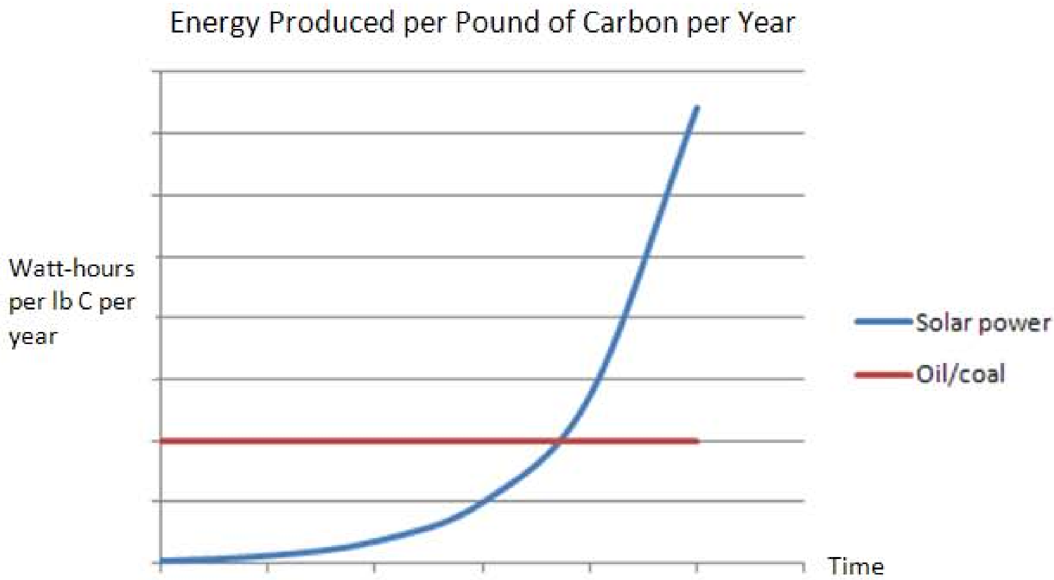

Here, the energy produced by solar power per pound of carbon increases with time because in that time, we will be supplementing (and later replacing) carbon-dependent plants with solar-powered plants. The crossover point denotes when the solar cells will be self-sufficient; that is, when their use will be just as beneficial as fossil fuel use (from an energy standpoint). However, even at this point, they are overall a better energy means than coal and oil because they pollute the environment less, and, as the graph shows, their energy efficiency in comparison to fossil fuels will continue to increase.