University of Arkansas Microelectronics-Photonics Graduate Program

PhD Candidacy Exam – March 2008

Materials Section of the Exam

PROBLEM TO BE SOLVED

With growing concern over future sources of energy, more and more researchers turn to the sun, the ultimate source of energy for our earth. A solar cell is a device that converts solar energy into electricity. Currently, silicon wafer-based solar cells dominate commercial production, but solar cells based on epitaxial layers of semiconductors are expensive and mainly used for the space market. However, a growing number of novel approaches for the next generation of solar cells are being developed, mainly based on nanomaterials, polymers, or some hybrid of the two.

You are the chief engineer of a company that produces solar cells for NASA on a Mars mission. Your job is to develop new materials to serve as light absorbers and charge carriers, to achieve the highest efficiency of energy conversion with competitive cost. You should clearly explain the advantage of your material design, how it will be used as a solar cell, and how it can be competitive as a new product. You need to compare your material design and solar concept with other new ideas for a new generation of solar cells discussed in the literature along with existing approaches for solar cells. You must also evaluate the required equipment, infrastructure, time for development, and the resulting cost of implementing this technology.

More specifically, the CEO has requested that you investigate ***quantitatively*** the magnitude of the effect of the variation of the material parameters on the performance of the solar cell. For example, for a semiconductor nanostructure, what change would be expected for small changes in the composition of the nanostructure? Moreover, is this change sufficient to warrant an investment in research of this parameter? Even more important, what other parameters should you investigate in order to make an effective report to your CEO?

In fact, your answer to this question should be a 15 page report that provides the guidance that your CEO needs to make a wise decision on a course of action or a go or not-go decision. This means that you must consider such factors as:

1. How you arrived at a material concept and how it compares with others
2. Growth of the material structure
3. Characterization of the material structure and performance important to this application
4. Incorporation of the structure into a useful device
5. Fabrication details of that useful device and how it will be tested
6. Definition of the market(s) served by the new device
7. Competitive analysis of this new device against current commercial devices

YOUR DELIVERABLE

Your job is to develop and evaluate a new material idea ***in detail, (note the stress on – "in detail"),*** and include an implementation plan for realization of an integrated material system in six months, with the first prototype device completed in one year. Your 15 page maximum length internal report will be shared and critiqued by your CEO and your fellow corporate officers. Be sure you address at least all of the following in your report:

Current Research - What is already being done in these areas by other researchers, companies and governmental institutions? The current state-of-the-art for both the underlying science and the device concept must be described in detail using numbers, making use of diverse resources such as science literature, journals, conference proceedings, the internet, patents or other sources of existing public knowledge. Do not forget to describe conjecture of upcoming technologies that could affect the competitive position of the material system or device concept that you propose to investigate. ***Be sure to cite all references that you use and to quote any word-for-word transfer to your report.***

Specific Material Systems – Carefully describe the material system you plan to use by including any difficulties you may expect during fabrication, such as intermixing or interface issues that may affect performance and how you will monitor and overcome them. Try to draw on the current state-of-the-art to provide assurance or expectation of success. Discuss the current state-of-the-art as well as where the technology needs to be developed to meet the need and cost requirements. Be sure to address both the material and engineering issues of any proposed device concept, while carefully explaining performance considerations and any cost-performance tradeoffs.

Characterization – Give a detailed list of desired specifications for both the integrated nanoscale material system and device concept that you propose. Discuss the available nanoscale growth and/or fabrication approaches that can do the job, with strong justification for your choice by discussing how close to specifications you expect to come.

Device Concepts – Be sure to give the underlying science behind all device concepts that you propose as well as the specifications you expect to reach. Specifically discuss expected variations in device performance against expected variation in the materials and/or device fabrication variation (including specific numerical calculations).

Manufacturing Flow – Describe the manufacturing process flow and the various pieces of equipment needed to fabricate and characterize the material system and proposed device. What equipment is available off-the-shelf, and what needs to be developed?

Testing and Qualification - Describe how the integrated nanoscale material systems that you propose and any corresponding devices will be tested and qualified, both for performance and for reliability. Do not forget to include the necessary testing needed to qualify your device for NASA space applications in general and for the Mars mission in particular.

Cost Analysis – At least in qualitative terms, describe the factors that will enter into the cost analysis for researching the integrated material systems as well as for fabricating potential products at volumes adequate to supply NASA Mars missions. If there are other potential markets for your devices they may be briefly introduced if it affects the profitability plan in a significant fashion. Use this as an introduction to then discuss your expectations of the competitiveness of your product and what would be the expected return on investment, fully explaining your assumptions.

Intellectual Property - List in rank order of importance all commercial, academic, and governmental IP sources that were consulted while formulating the answer, including key important reference data, as an appendix to this exam. For instance, if the IP source is a patent, include the patent number; title; inventor name; and assignee name. (The full list will not be counted as part of the 15-page limit.) The most competitive materials and device concepts should be discussed within the 15-page document, making comparisons of strengths and weaknesses of these materials systems or device concepts relative to your own.

Most importantly - this is just a minimum list of issues you might consider. There may be many more. The point is that your report ***should contain the evidence*** needed to make an effective and compelling case to your CEO in order to insure that she makes the right decision.

Hint - Your report should read like a story – one logical step followed by another. This will help you stay focused! Re-read along the way to be sure that you have one logical step followed by another.