

University of Arkansas Microelectronics-Photonics Graduate Program
PhD Candidacy Exam – March 2006

Advanced Materials, Processing, And
Devices at the Micro to Nano Scale as Applied To Photonics

PROBLEM TO BE SOLVED

You are the chief engineer of a company that currently produces building materials, with an especially strong market presence in window materials. The CEO of the company is interested in the potential to develop a range of capabilities that might be incorporated into “smart windows”. The CEO believes that the existing distribution channels can be used very effectively to bring advanced products to market, and that it is the right time to develop a new product.

New products could include, for example, advanced solar blinds or light redirecting components in windows to optimize both comfort and lighting in buildings. Optimized use of lighting is one key area of emphasis, but there is a desire to simultaneously make use of emerging sensor technologies and to market a product that is very aesthetically pleasing. Clever application of occupancy sensors can lead to optimization of room lighting (both magnitude and wavelength distribution) for comfort (temperature, glare, etc.) or for harvesting energy and minimizing radiative losses. Security sensors could be used to determine when an intruder has approached the home, alerting the smart window to become opaque to visible light, while enabling infrared viewing and imaging of the intruder by the occupant. (The same functionality might allow for improved energy efficiency, with infrared radiation blocked during evening hours to minimize losses.) The CEO is a real dreamer, and has imagined that these windows could also be used as displays, reprogrammable to appear as either a solid color panel or a low resolution abstract art panel in the evenings. All of this technology appears to be somewhat available, but there may be significant technical obstacles in bringing a new system to market. It is not known whether it is even possible to deliver on all of the things that the CEO is demanding, or if it might be possible to have a series of products whose prices would reflect basic to full functionality.

Your management team is very interested in expanding into smart windows (see, they listen to the CEO), but needs guidance on how to begin product development, which features will require R&D investments, and which can be provided mostly by creative adaptation of existing technology. Your job is to study the requirements for providing the desired functionality and to make recommendations on an overall approach, with heavy emphasis on the photonic materials that are currently seen as being a key enabling technology. You should develop at least one proposed design for a smart window that can begin to deliver on the overall vision. Your report, with its technical analysis and cost/benefit analysis, will be the primary document used by your company to define the product specifications used to develop this new product line.

To begin with, you should provide a comprehensive survey of competitive technologies, along with analysis of strengths and weaknesses of each approach, and make recommendations for your company's product development. Specifically on this recommended approach you need to evaluate the required equipment, infrastructure and the resulting cost of implementing this technology. You should clearly (but briefly) explain smart windows technology including, for example, bi-directional transmission (or reflection) distribution functions along with discussion of any angular and wavelength dependences. Explain your rationale on why your company should or should not attempt to adapt current technologies or develop new technology to produce smart windows.

The objective is for the smart windows to meet the following requirements. Clearly explain any issues that will prevent these goals from being met:

- Adjust visible light transmission (reflection) from 5% to 95% within 0.5 seconds
- Adjust infrared transmission from 5% to 50% (wavelength chosen to match the detector of your choosing) within 2 seconds
- Tailor both visible and IR transmission (reflection) on demand to balance comfort and energy efficiency in response to changing conditions
- Thermal conductivity at least as low as conventional windows
- Sales price of less than \$2,000 in volumes of ten thousand units per year, for 1.0 X 1.0 meter window size
- Reliable operation with minimal degradation over a five year life in a moderate climate
- Functional year-round at any latitude
- Convert to minimum 256 color display on demand

YOUR DELIVERABLE

Your task is to write an internal proposal for your corporate officers describing your approach to this issue. Be sure you address all of the following:

Current Technologies - What is already being done in this area by other researchers, companies and governmental institutions? The current state-of-the-art for both the science and the implementation should be described, making use of diverse resources such as science literature, journals, conference proceedings, the internet, patents or other sources of existing public knowledge. Be sure to cite all references used.

Your Proposed Implementations - Describe in detail how and where you plan to use smart windows and how the user will benefit from these applications. Include both the scientific and engineering basis and the method of applying this to a workable solution. Carefully explain performance considerations and any cost-performance tradeoffs.

Other Issues – Address any other issues of major importance

Manufacturing Flow - Detail the step-by-step procedure for making these structures in a form useful in manufacturing.

Testing and Qualification - Describe a set of tests and demonstrations that you will use to demonstrate the effectiveness of your approach.

Cost Analysis - Perform a cost analysis that includes, at least, acquisition of raw materials, labor rates, costs per operation, etc. assuming quantities of 10,000 windows per year. You may exclude from your analysis possible additional costs in such infrastructure areas as human resources, facilities engineering, janitorial and grounds, upper level management, etc. You must include all direct manufacturing costs, both startup and continuing; and you must discuss explicitly space and personnel requirements to set up a stand-alone product line. Generic per process costs for various manufacturing methods can be used, as long as they are rationally applied.

Intellectual Property - List in rank order of importance all IP sources that were consulted while formulating the answer, including the full list of examined documents along with 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 three that are the most significant threats to your solution should be discussed within the 15-page document, making comparisons of strengths and weaknesses of these approaches relative to your own.