Philips Laboratories

A Novel Microminiature Light Source Technology

Companies located in the Pacific Rim dominated the market for miniaturized circuitry and lighting applications from the 1980s to the early 1990s. During that time, U.S. firms fell far enough behind that they had trouble keeping a foothold in the marketplace. In 1993, Philips Laboratories applied for Advanced Technology Program (ATP) support to research a method to use microcavities as small as 1 mm in the company's microlamp research and to develop a prototype for industrial and consumer applications. Philips' proposed research would focus on creating electrodeless microlamps as well as microlamps with both conventional and thick-film electrodes. Toward the end of the ATP-funded project, Philips focused mainly on thick-film tungsten electrodes in 1-mm cavities, since these showed the most promise. All research and knowledge from the ATP-funded Philips Laboratories project was transferred to Philips Lighting after the close of the project in order to facilitate microlamp commercialization. Ultimately, Philips Lighting could not commercialize the product at prices low enough to compete with microlamps already on the market, so the company abandoned plans to bring a product to market.

COMPOSITE PERFORMANCE SCORE
(based on a four star rating)
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Research and data for Status Report 93-01-0045 were collected during October - December 2001.

Pacific Rim Firms Dominate the Market

Between the late 1970s and the early 1990s, miniaturization emerged as one of the most significant design trends for consumer and military products. Companies with strong technical competencies in miniaturization processes, such as precision machining and micromachining, gained considerable competitive advantages in the marketplace. These companies, largely based in Japan, used their strong miniaturization capabilities to design and manufacture electronic and optical products that were higher performing, lighter, and more rugged than those made by companies who lacked miniaturization expertise. The progress by Pacific Rim-based companies negatively impacted the health and stability of the electronics industry in the United States, which, as of the early 1990s, had not developed a comparable level of competency in miniaturization.

Moreover, because miniaturization technology significantly impacts the manufacturing, machining, lighting, and display industries, companies based in the Pacific Rim maintained a significant advantage in those industries. In 1993, however, Philips Laboratories developed a research project to use miniaturization technology to create a small, powerful, efficient lamp for lighting and display options.

U.S. Firms Must Improve in Order To Compete

By the 1990s, microlamps manufactured outside the United States were coming to market in automobile lighting, projection televisions, and backlights for laptop computers. However, the U.S. lighting industry had not been able to capture the benefits of miniaturization. These microlamps were generating significant revenue for non-U.S. businesses. For example, the automotive headlamp market was $389 million annually in 1993 and was expected to grow to $496 million by 1997. The projection television and laptop computer marketplaces, while smaller overall, were experiencing even more rapid growth. Without improved miniaturization capabilities, U.S. manufacturers could not produce lamps that were small enough, bright enough, cheap enough, or capable of being viewed at a wide enough angle to capture market share from the Asian companies.

Technical Benefits of the Proposed Technology

Philips Laboratories proposed to develop ultra-miniature light sources that were less than 1 mm in diameter, which would be significantly smaller than the Japanese-produced 5-inch lights, the smallest available at the time. This radically new approach would use microfabrication techniques to generate very small sealed cavities in transparent substrates. Those cavities, when created and activated properly, would serve as the ultra-small light sources. The sealed cavities would be formed by etching and wafer-bonding techniques that were already established within other industries.

Miniaturization emerged as one of the most significant design trends for consumer and military products.

The more difficult aspects of the proposed technology involved investigating the emissive properties of electrical discharges within the sealed cavities in both an inert state and when filled (also known as "dosed") with different materials. One of the expected advantages of the miniature cavity was its ability to sustain much higher pressures because of its small size. The cavity was expected to withstand several hundred atmospheres of pressure; and since light output (lumen) efficiency increases at higher pressures, the ultra-small light sources would be highly efficient. Moreover, the smaller size would enable wider viewing angles and more light sources packed onto a substrate, making the light more visible and of better quality.

Philips' Research Project Promises Cost and Environmental Advantages

Philips determined that there were three areas of potential broad-based benefits that could flow from a successful project. First, given that the Pacific Rim countries' miniaturization skills clearly dominated the world market, any effort to bring market share back to the United States had the potential to create significant economic benefits through increased domestic manufacturing jobs and decreased reliance on imports.

Furthermore, the innovation Philips proposed could also reduce the cost of the ultra-miniature light sources produced in Japan. For example, before the ATP-funded project began in 1994, the typical cost of processing a 5-inch substrate for these light sources, through a sequence of integrated circuit fabrication steps, was $100. Since the proposed microlamps were smaller than their Pacific Rim counterparts, and the manufacturing process was simpler, the cost of processing the 1-mm ultra-miniature light source would be approximately 10 cents per lamp, a 99.9-percent decrease in the cost per lamp.

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The second broad-based benefit from Philips' proposed innovation was the impact that would accrue to many downstream U.S. industries. If the proposed technology were successful, the new range of U.S.-manufactured ultra-miniature light sources would be of interest to the lighting, automotive, consumer electronics, and professional equipment industries within the United States. However, in order to remain focused and to have a better chance of success, Philips decided to limit its miniaturization project to research for lighting and display applications.

The third potential benefit of the new technology was environmental. Philips' proposal would create lighting sources that used far less mercury than any lights available on the market. Because even small amounts of mercury in cast-off lamps leech into the soil and pollute large areas, there is a recognized need to reduce mercury usage. If successful, the project would enable effective lighting sources with a significantly lower risk of environmental pollution.

Philips Seeks Public Funds To Help Develop Technology

Despite these potential benefits, substantial technical and business challenges prevented Philips from funding the research internally. In 1990, several years before submitting their ATP proposal, Philips had conducted a preliminary investigation into this new technology. Their research suggested that the fabrication, dosing, and sealing of microcavities were possible for these ultra-miniature lighting sources. The technical risks lay with conducting a full-scale examination of the physical phenomenon of generating specific types and strengths of light within very small cavities. The research project called for full investigation of a large variety of discharges in order to minimize the amount of mercury necessary for lighting. In addition, the microcavity walls would need to be engineered precisely to prevent distortion and loss of energy that would adversely affect lumen efficiency. The microcavity engineering risk was substantial because U.S.-based lighting industry knowledge in 1993 was based on assumptions from lighting results in much larger cavities. Putting the physics and models to practice within a 1-mm cavity, however, was significantly more difficult.

The project's business risks were formidable given the complete industry domination by companies based in the Pacific Rim. The cost of manufacturing labor was significantly less in Japan than in the United States. Therefore, savings from a successful project would have to be significant enough to make up for the labor cost disadvantage if U.S. companies' microlamps were to compete in the global marketplace. ATP, satisfied that Philips met the technical criteria for funding, awarded the company cost-shared funds in January 1994.

Project Focuses on Three Types of Lamps

As part of its process to create an ultra-miniature light source, Philips studied light emission within three forms of lamps: the electrodeless microlamp, the electroded microlamp with conventional electrodes, and the electroded microlamp with thick-film electrodes.

Electrodeless Microlamp

Philips had fabricated sealed cavities in quartz substrates prior to the start of the ATP-funded project. They believed a similar process could be developed for glass, sapphire, and other substrates. The process used to fabricate the miniature cavities involved four steps. First, a masking layer is deposited on the wafer substrate and is patterned. Second, the quartz substrate is then etched through the openings in the cavity. Third, the cavity is filled with a dosing material. Finally, another wafer, in which similar cavities have been etched, is aligned with the initial wafer and bonded to it in the appropriate ambient gas using fusion-wafer bonding. This process forms a sealed cavity that contains the dosing material and the gas. As a result of the company's research during this ATP project, Philips succeeded in fabricating sealed cavities that contained a dose of mercury and argon gas. Such cavities can be excited with radio frequency or microwave power, thereby creating a discharge microlamp. The microlamp, however, did not produce commercial-quality light. Therefore, Philips continued its research with electroded microlamps.

Electoded Microlamp with Conventional Electrodes

Philips determined that the scientific and technical issues related to these electroded microlamps were more difficult than the electrodeless microlamp, but the potential for efficient lighting was greater. During the process of incorporating the electrode into the sealed cavity, careful steps needed to be taken to ensure that contamination did not occur within the cavity. If contamination did occur, the microlamps would not operate properly, if at all. Furthermore, the temperature within the sealed cavity, when excited by a current, had to be regulated to prevent evaporation of the vapors inside and to prevent the electrodes from melting.

The cost of manufacturing microlamps within Philips Lighting was too high to effectively compete with other products on the market.

After developing several designs and prototypes, Philips was able to create three electroded microlamps. The first was an electroded, high-pressure mercury microlamp and the second was an electroded high-pressure mercury microlamp that contained arcs of just 1 mm. The 1-mm arcs made the second microlamp well-suited for projection applications. A third microlamp was developed with electrodes located on one side, a design that enabled the microlamp to be illuminated using low electrical current. As a result, small apparatuses that require low-wattage light could incorporate this microlamp.

Electroded Microlamp with Thick-Film Electrodes
In order to create microlamps for use in a wider array of lighting applications, Philips also researched electroded microlamps with thick-film electrodes. In its proposal to ATP, Philips indicated that tungsten would be a good electrode candidate because of its high melting point, good conductivity, and electron-emission properties. The key step in the formation of the tungsten thick-film electrodes would be the deposition of tungsten films on quartz substrates without significant warping, cracking, or peeling. Philips simultaneously investigated several different techniques to achieve these requirements, including low-pressure chemical vapor deposition, plasma-enhanced chemical vapor deposition, laser ablation, and sintering of tungsten paste. At the conclusion of the ATP-funded project, Philips Laboratories scientists and engineers had developed an impressive research file on the emissive properties of tungsten thick-film electrodes.

Cost Pressures Limit Commercialization

The entire body of knowledge developed during this ATP-funded project was transferred to Philips Lighting, a separate company that would work to make the final adjustments on, and commercialization of, the thick-film electroded microlamps and conventional electroded microlamps. Ultimately, however, the cost of manufacturing microlamps within Philips Lighting was too high to effectively compete with other products on the market. Philips Lighting management decided in 1998 not to market any of these products commercially, but to retain them for future internal research and development activities.

Project Knowledge Is Disseminated

Though Philips Lighting's management decision ended plans to bring products resulting from this ATP-funded research to market, the research conducted at Philips Laboratories was made available to other interested parties through a number of knowledge-dissemination channels. Three patents were granted for knowledge directly related to this ATP project, and applications were submitted for nine others. Moreover, an article was submitted for publication to the professional journal, Applied Physics Letters, and presentations were made at four industry symposia.

Conclusion

ATP awarded Philips $1.43 million in cost-shared funds to pursue miniaturization technology for microlamps. The research project examined electrodeless microlamps and microlamps with traditional and thick-film electrodes. Tungsten thick-film electroded microlamps showed the most progress, and Philips Laboratories developed a large body of research on this technology. All knowledge was transferred to Philips Lighting for commercialization after the end of the ATP-funded project in 1997. However, the cost of tungsten thick-film electrodes was still too high for commercialization, and no products resulted.

PROJECT HIGHLIGHTS
Philips Laboratories

Project Title: A Novel Microminiature Light Source Technology

Project: To develop techniques to produce microminiaturized, high-pressure discharge lamps using etched cavities in quartz or sapphire wafers for lighting and display applications.

Duration: 2/15/1994-2/14/1997
ATP Number: 93-01-0045

Funding (in thousands):**

ATP Final Cost	$1,432	28%
Participant Final Cost	3,576	72%
Total	$5,008	

Accomplishments: As a result of this ATP project, Philips successfully achieved several broad objectives, which in the future could lead to the development of microminiature, high-intensity discharge lamps. These successes include the development of an electrodeless microlamp and the development of an electroded microlamp fabricated with conventional electrodes. Philips also developed tungsten films as thick as 20 microns with minimal warping, cracking, or peeling by using a plasma-enhanced chemical vapor deposition process. This process is pivotal to the future development of electroded microlamps fabricated with thick-film electrodes. In addition, Philips acquired significant knowledge from this project, which led to the granting of five patents and the publication of several articles. Patents for technologies related to the ATP project include:

- "Microlamp incorporating light collection and display functions"
  (No. 5,574,327: filed June 7, 1995, granted November 12, 1996)
- "Flat panel light source for liquid crystal displays"
  (No. 5,808,410: filed June 7, 1995, granted September 15, 1998)
- "Gas discharge lamps fabricated by micromachined transparent substrates"
  (No. 5,965,976: filed December 19, 1997, granted October 12, 1999)

Commercialization Status: Because manufacturing costs remained too high, commercialization of this breakthrough technology has not been initiated. However, Philips and the industry are ready to provide the technology and its related products when a scale-up need arises.

Outlook: As the demand for microminiature light sources increases, so will the need to provide a scaled-up production method. As a result, the outlook for this microminiature light source technology is promising, especially due to the lighting, automotive, consumer electronics, and professional equipment manufacturers' continuous search for methods to increase product efficiencies. In addition, the knowledge spillover from this ATP project is extensive. By May 2001, 32 additional patents had been spawned from the initial 5, evidence that the market is very interested in the technology that resulted from this project and that there could be demand for microminiature lamps in the near future.

Composite Performance Score: *

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** As of December 9, 1997, large single applicant firms are required to pay 60% of all ATP project costs. Prior to this date, single applicant firms, regardless of size, were required to pay indirect costs.

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