FINAL TECHNICAL REPORT SOLID-STATE CERAMIC LIGHTING PROJECT

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ABSTRACT

Meadow River Enterprises, Inc. (MRE) and the New York State College of Ceramics at Alfred University (NYSCC) received a DOE cooperative agreement award in September 1999 to develop an energy-efficient Solid-State Ceramic Lamp (SSCL). The program spanned a nominal two(2) year period ending in February of 2002. The federal contribution to the program totaled \$1.6 million supporting approximately 78% of the program costs.

The SSCL is a rugged electroluminescent lamp designed for outdoor applications. MRE has filed a provisional patent for this "second generation" technology and currently produces and markets blue-green phosphor SSCL devices. White phosphor SSCL devices are also available in prototype quantities. In addition to reducing energy consumption, the ceramic EL lamp offers several economic and societal advantages including lower lifecycle costs and reduced "light pollution". Significant further performance improvements are possible but will require a dramatic change in device physical construction related to the use of micro-powder materials and processes. The subject "second-generation" program spans a 27 month period and combines the materials and processing expertise of NYSCC, the manufacturing expertise of Meadow River Enterprises, and the phosphor development expertise of OSRAM Sylvania to develop an improved SSCL system. The development plan also includes important contributions by Marshall University (a part of the West Virginia University system).

All primary development objectives have been achieved with the exception of improved phosphor powders. The performance characteristics of the first generation SSCL devices were carefully analyzed in year 1 and a second generation lamp was defined and optimized in year 2. The provisional patent was "perfected" through a comprehensive patent application filed in November 2002. Lamp efficiency was improved more than 2:1.

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1.0 INTRODUCTION

HISTORICAL PERSPECTIVE

Electroluminescence (EL) in ZnS:Cu powders was discovered in 1936. Spurred by the development of transparent electrodes, considerable academic and industrial research in the 1950's was directed towards developing EL devices as "the light source of the future". Despite significant advancements in the EL technology throughout the decade, devices which achieved useful light levels were plagued with low lifetimes (~500 hours) for thick-film plastic devices and daunting production complexity for ceramic systems. As a result of the production complexity, work on ceramic systems was largely discontinued. Since the early 1960's, the bulk of EL research has focused on information display technology and has resulted in the commercialization of full-color displays based on thin-film technology. In 1990, the Durel corporation demonstrated a flexible (plastic) EL lamp based on thick-film technology, extending lifetime through the use of encapsulated phosphor powders. Today, plastic EL lamps from multiple suppliers based on thick and thin-film technology are widely used as backlights in liquid crystal information displays (portable monitors, wristwatches, etc.) and in a variety of aviation applications where nightvision is of concern. Both highest light output and maximum conversion efficiency are achieved with blue-green phosphor which also has an ideal spectrum for aviation nightvision applications. Amber and white phosphor mixes are available with reduced performance levels. For thick-film plastic EL devices, the current state-of-the-art is approaching 15 lumens per watt, a dramatic improvement from the 2 lumens per watt typical of the first-generation devices. The key problems are environmental sensitivity, mechanical fragility, and a severe lifetime reduction at high intensity levels. Intensity levels exceeding 100 ft-lamberts are possible for short periods of time.

In 1997, Meadow River Enterprises, Inc. (MRE) became aware of a promising ceramic EL configuration and in early 1998 successfully negotiated the acquisition of US Patent 4,482,580. This lamp is comprised of a steel substrate with fused layers of ceramic and phosphor materials. However, production yields based on this technology were low and the conversion efficiency was poor. New materials and new production processes were needed to realize the potential of light-emitting ceramics.

In September of 1999, a two(2) year R&D effort was initiated through a cooperative agreement with the U.S. Department of Energy (DE-FC26-99FT40631) with federal funding of \$1.6 million in a total effort exceeding \$2 million. The development team included the New York State College of Ceramics at Alfred University in Alfred, NY, Marshall University in Huntington, WV, and OSRAM Sylvania in Towanda, PA. The result is a new, high efficiency, light-emitting ceramic termed an "electroceramесcent" lamp (ECL).

ECL OVERVIEW

Figure 1 illustrates the basic design of an electroceramесcent lamp (ECL). The panel is comprised of a series of layers deposited upon a stainless steel substrate. An AC

potential applied across the electrodes (the steel substrate and the transparent conducting oxide) introduces a high field across the phosphor layer which causes electrons to accelerate to high energies and to activate luminescent centers in the phosphor. Light is produced when the centers relax to their ground state. The ECL panel can be driven by an AC power source over a wide range of voltages and frequency. Transformers and inverters are used to convert the primary power source (utility, battery, solar) to an appropriate voltage (typically 90 to 250 volts RMS) and frequency (typically 60 to 1000 Hz) for optimum ECL performance. Typical illumination levels are in the 1 to 10 foot-lamberts range.

Figure 1. Schematic of ECL panel

. The multilayer device is a sophisticated light-emitting ceramic system designed and produced using state-of-the-art fabrication technology. The first commercial lamp products are now available using this patent-pending technology.

2.0 EXECUTIVE SUMMARY

BACKGROUND

Residential and commercial lighting account for 14 % of the total national energy use. The Department of Energy recognizes the potential for a 50% decrease in lighting energy consumption by the year 2010.[1] To achieve this reduction, advances in lighting systems technology are required including sources, fixtures, and controls as well as a more sophisticated understanding of user needs and preferences. Brighter is not necessarily better! Light “pollution” is a growing problem endangering nighttime ambiance in many dimensions from garish displays of advertising excess to dark sky concerns. Since many building areas (and surrounding grounds) are lighted at night primarily for ingress and egress, there is a leveraged opportunity to combine low

background levels of illumination with highly visible, but non-polluting, information and safety “objects” (controls, general signage, security warnings, stair edges, path markers, hazard markers, etc.).

In September 1999, Meadow River Enterprises, Inc. (MRE) was awarded a cooperative agreement under the “Energy Efficient Building Equipment and Envelope Technologies Program” (PS No. DE-PS26-99FT40528) to develop an energy-efficient Solid-State Ceramic Lamp (SSCL). The SSCL is a rugged electroluminescent lamp. MRE is the U.S. Patent holder for this technology and currently produces and markets “first-generation” blue-green phosphor SSCL devices in prototype quantities. Experimental units of a white SSCL have been fabricated that are potentially well suited to a variety of lighting applications (indoor and outdoor, commercial and residential). In addition to reducing energy consumption, the ceramic EL lamp offers several economic and societal advantages including lower lifecycle costs and reduced “light pollution”. While SSCL performance is promising, improvements related to materials design and process development are required for the device to compete with other competitive lighting sources. The development program was based on a 24 month plan that combines the materials and processing expertise of the New York State College of Ceramics at Alfred University (NYSCC), the manufacturing expertise of Meadow River Enterprises, and the phosphor development expertise of OSRAM Sylvania to develop an improved SSCL system with special emphasis on the white phosphor. The development plan also includes important contributions by the DOE National Renewable Energy Lab (NREL) and Marshall University (a part of the West Virginia University system).

OBJECTIVES & STATUS

The primary objective of the two(2) year research program was the development of a robust ceramic electroluminescent lighting system competitive (performance and price) with the more fragile plastic EL devices. Exterior applications (including landscape areas) with full weather exposure constitute the target operating environment. The two(2) year effort included a detailed evaluation of the existing “First Generation” SSCL lamp, definition and development of the “Second Generation” SSCL product, termed an “electroceramesscent” lamp (ECL), and a qualification test program for prototype ECL lamps.

The primary objective of developing a robust, competitive ceramic electroluminescent lighting system was achieved including a white phosphor lamp. However, no significant improvement in phosphor powders was achieved. The provisional patent was “perfected” through a comprehensive patent application filed in November 2002.

MARKET DEVELOPMENT

An aggressive product evaluation program was completed with the Appalachian Transportation Institute (ATI) at Marshall University in Huntington, WV. A variety of ECL signage was evaluated for highway applications over a period of approximately 12 months. The effort included visibility tests under laboratory simulated fog conditions. Future plans include evaluation of ECL applications in the National Park System.

CONCLUSIONS

All critical objectives have been achieved. The analyses of the first generation SSCL materials and processes provided clear explanations for all primary performance characteristics and anomalies. The "Second Generation" ECL product provides performance competitive with plastic EL in outdoor environments.

3.0 EXPERIMENTAL

3.1 Design Concept

The historic body of work relating to ceramic electroluminescent devices, now largely in the public domain, is for the most part conceptual. Validation has been limited to small area devices with few specific performance requirements. In fact, this technology baseline mostly served to confirm that useful devices were possible but failed to define integrated material systems and processes which could realize this potential in a commercially viable product. For example under U. S. patent 4,482,580 (1984), MRE previously attempted to develop and commercialize a ceramic lamp. However, the manufacturing yields of this design proved too low, and the power dissipation levels too high, to successfully compete with plastic EL devices. The broad objective of the subject cooperative R&D effort was to more fully realize the potential of the ceramic EL technology.

Year 1 of the R&D effort (see Ref 4, Year 1 Topical Report) identified significant omissions in the set of required device attributes that had been previously considered with special emphasis on the complex interactions between the material compositions in the various device layers. The special challenges of large area devices (e.g. > 1 sq-ft) both in terms of production cost and performance had not been considered in previous efforts. The primary objective of the year 2 effort was to develop and demonstrate an integrated set of materials and processes which achieve a dramatic improvement in both ceramic EL performance and cost relative to the prior art. This new fabrication methodology and associated materials system are applicable to large areas and enables devices which are superior to plastic EL in many important applications, including those with severe environmental exposure requirements.

3.2 Fabrication Methods and Equipment

The ECL device includes a combination of liquid spray and electrostatic spray sequences which support application to large areas in a continuous manufacturing flow while assuring controlled bubble structure and layer uniformity. Each of these spray stations was custom designed based on proprietary methods. A custom designed conveyor furnace was used to sequentially fire each ceramic layer. The furnace includes an integrated spray pyrolysis section to create a transparent conductive tin oxide layer as the top electrode. Under computer control, the various furnace zones provide appropriate pre-heat, fusion, and cool-down regions meeting proprietary thermal profile requirements.

4.0 RESULTS AND DISCUSSION

A conceptual layout for a typical ECL lamp was previously illustrated in Figure 1. A metal substrate provides structural support while also serving as a base electrode. An insulating layer is constructed on the substrate providing break-down isolation for an overlying ceramic matrix encasing the EL phosphor. A transparent top electrode

completes the electrical circuit permitting an intense AC field to be established across the ceramic stack. A transparent ceramic cover layer is used to protect the top electrode and the phosphor layer from the ambient environment. Given a nominal 10:1 ratio between the dielectric constant of the insulation layer relative to the phosphor layer, most of the applied voltage will appear across the ceramic matrix containing the phosphor. Yet in the event of short-circuit through the phosphor layer, the insulating layer will limit the current and help minimize degradation in device performance. This model is deceptively simplistic because the ceramic stack is a blended mechanical, chemical, electrical, and optical system formed through a sequence of molten states, each with a unique time-temperature profile providing the opportunity for diffusion of various constituents between layers and contributing complex residual mechanical stresses upon cool-down to ambient temperature.

In terms of design priorities, a fundamental requirement is that the stack must bond together mechanically with minimal distortions and fracturing due to residual stresses arising from mismatched coefficients of thermal expansion which are compounded by temperature gradients during processing. The cool-down time-temperature profile is often as important as the peak temperatures reached. The metal-to-ceramic bond lines at the substrate are particularly troublesome because the coefficients of thermal expansion cannot be exactly matched and the constituents in the ceramic mix which contribute to a strong bond (generally metal oxides) have an adverse effect on the electrical properties of the insulation layer. Further, given device areas of several square feet and the inevitable temperature gradients induced by the high temperature oven system, there will be microcracking penetrating multiple levels. In practical terms, the device design must accommodate a significant level of statistically certain imperfection while minimizing the adverse performance effects. Therefore optimum device performance is not a simple summation of optimum components. The complexity of the ceramic EL system, and the difficulty in achieving viable commercialization in prior art devices, arises in no small part from these non-linear interactions, especially including a tolerance for some number of localized faults in large area devices.

Most prior art ceramic EL designs used low carbon enameling steel as the substrate providing a marginal thermal expansion coefficient match with an overlying ceramic layer. The mechanical bond to the substrate was achieved through an overlying semiconductive ceramic layer formed by a materials mix containing titanium oxide which becomes semiconducting upon diffusion of iron from the steel substrate. The conductivity of this semiconducting ceramic was sufficiently high as to substantially reduce the power dissipation in this layer. The dielectric layer was formed as a matrix of finely ground barium titanate combined with a glass which also contained titanium oxide. This layer served to slow the diffusion of iron toward the vulnerable phosphor layer while providing improved break-down protection. The EL phosphor was encased in a glass matrix with an overlying transparent conductive top electrode. A protective top cover was typically provided by bonding a rolled glass sheet to the top electrode.

This materials system does not provide an adequate match in thermal expansion coefficients between the substrate and the semiconducting layer. Hence in large area planar devices (e.g. panels >1 sq-ft), the panels will distort during processing increasing the magnitude of thermal gradients induced by the oven system and contributing to microcracking in the various ceramic layers. In fact, the residual stresses noted in commercialization attempts based on these methods were such that a post-processing mechanical stress relief step (involving bombardment of the substrate rear surface with small metal spheres in a fashion similar to sandblasting) was required to regain a flat surface. Further, the mechanical adhesion between the semiconducting layer and the substrate is significantly weakened by the detailed chemistry of the interaction of the iron oxide interface (which largely provides the bond) with the substantial titanium oxide constituent in the overlying ceramic. In addition, the surface of a low carbon steel substrate is a major processing contaminate as a result of flaking due to oxidation at the high temperatures required for the ceramic melding. By using specially processed stainless steel, the ECL device achieves a substantially improved match in thermal expansion coefficients, a substantially improved level of mechanical adhesion, and a total elimination of the flaking debris problem.

The dielectric layer in prior art configurations was intended to provide a barrier for further diffusion of iron beyond the semiconducting layer. The barium titanate is relatively immune because the processing temperatures are well below its melting point. However, the glass constituent of the dielectric layer will support iron diffusion introducing possible contamination of the zinc sulfide phosphor layer which is particularly sensitive to iron. The use of titanium oxide in this glass, which potentially increases the dielectric constant, to trap the iron also results in semiconducting behavior and a degraded dissipation factor for the dielectric layer. Iron diffusion effects are the most likely reason for the inferior dissipation levels realized in previous designs. The ECL device uses a proprietary diffusion agent for the semiconducting layer and a different barrier strategy to limit diffusion into and beyond the dielectric layer, leading to superior overall dissipation levels for the ECL device.

A rolled glass protective layer (used in previous designs) exhibits desirable durability properties. However, the organic bond material is combustible and in direct contact with the top electrode. In the event of localized voltage break-downs in the device, the peak temperatures are typically sufficient to carbonize the organic coating creating a permanent, highly visible damaged area. In general, all of the prior art configurations are vulnerable to voltage break-down effects resulting from microcracking which penetrates multiple levels in the ceramic stack. As previously noted, panels of any significant area will almost inevitably exhibit microcracks, layer thickness variations, and other defects sufficient to create minor electrical breakdowns. The manufacturing yield would be reduced to unacceptable levels if all panels initially exhibiting electrical breakdown were rejected. None of the prior art provides a means to electrically isolate the fault areas without substantial residual damage to device performance.. The ECL device provides current limiting in the semiconducting layer, a “fuse coating” as the top electrode, and a

ceramic layer overlying the electrode, all of which combine to isolate localized voltage break-downs without significant residual damage to device appearance or performance.

In addition, none of the prior art considers the electrochemical consequences of leakage currents flowing through ceramic top layers overlying and protecting the top electrode. Such leakage currents can result in severe electrochemical degradation of fused glass structures (see Ref. 5). The ECL device recognizes the importance of inhibiting such leakage currents and implements a strategy to insulate the entire electroceramescent device (especially including the rear surface of the substrate) in such a way that the top electrode can be held at earth ground potential while the substrate serves as the high potential electrode.

Manufacturing cost considerations are a major factor in assuring a competitive ceramic EL device. For many important application areas (e.g. commercial signage), a level of customization is required which limits the amount of special tooling that is practical. As a specific example, much of the prior art uses screen printing techniques for one or more layers which does not easily accommodate low quantities of customized designs nor large device areas. However, screen printing enables a level control which is important in assuring layer uniformity, bubble structure, etc. Liquid spray technology has also been used in prior art ceramic EL attempts. This technology is fully compatible with relatively low cost, continuous flow processing methods. However, the evaporation of the carriers in the liquid spray slurries and the melding of the glass frits into a ceramic solid introduce a bubble structure which can have major adverse consequences. Bubbles formed in one layer can migrate to another during the firing of a subsequent layers. The bubbles tend to grow in size as they migrate upward through the ceramic stack and can result in significant electrical and optical degradation, especially if they reach the phosphor layer. A proprietary optimized combination of liquid spray and E-spray systems was developed for the ECL lamp.

5.0 PATENT STATUS

The provisional filing was perfected in November 2002.

6.0 MARKET DEVELOPMENT

6.1 Electroceramescent Lighting Applications

Electroceramescent lighting (ECL) offers several potential advantages over traditional light sources, including:

- High visibility (direct, not reflected, area illumination)
- Low heat dissipation (no IR radiation)
- Low maintenance (no bulbs)
- Long life without catastrophic failure (up to 10 years)
- High visibility in adverse conditions (fog/smoke)
- High-quality light source (no glare, no flickering)

Numerical comparisons of the efficiency of EC lighting to traditional light sources are often misleading. For example, typical efficiency of incandescent and fluorescent lights exceed 15 and 75 lumens/watt (LPW), respectively, whereas the efficiency of an EC lamp may be as low as 4 LPW. Ironically, even a low efficiency EC lamp often uses dramatically less power than conventional light sources for a given task. For example, consider the sign shown in Figure 2. The 14' x 4' sign utilizes the older ceramic EL for letter illumination and operates on less than 25 W – approximately one-twentieth the energy required for the same sign if conventional T-12 high output fluorescent lamps (550 W) had been used. The gain results in large part from lighting the information rather than the sign. EC technology would further reduce the power demand to less than 12.5 watts. An additional substantial energy saving (typically 50%) could have been realized by forming the letters and symbol with laser cut ECL panels and literally lighting the individual characters. The flat, diffuse character of the ECL light produces virtually no glare or halo, even in adverse weather conditions. There is little wasted light. Reflected light configurations, widely used for internal and external signage, inherently waste much of the illumination energy lighting internal backlight cavities, the ground, or the sky. Typical ECL illumination levels are in the 1 to 10 foot-lambert range. Green and white phosphors are available.

Figure 2 – NREL Sign

Studies conducted by the United States Air Force in the 1980's demonstrated that EL lighting had several advantages over incandescent lighting in runway applications . Most notably, for equivalent power levels, EL lights were observed at greater distances than were incandescent lights. Moreover, the observation range of EL lights was not noticeably reduced during dust and haze conditions. These features present obvious advantages over conventional light sources for residential and commercial signs as well as for emergency lighting in industrial facilities. The Air Force study also recognized that EL is a high-quality light source without glare or flickering. Unlike incandescent lights, EL and ECL sources do not require energy-squandering diffusers to eliminate glare. In spite of dramatic differences in lumens/watt performance, the Air Force study demonstrated a human perception of equivalent brightness for an equivalent power level. One possible explanation is the unique spectrum and spatial sharpness of the EL or ECL light.

Spectral power distribution is another dimension of lighting economy. Our eyes are basically tetrachromatic: maximum sensitivity for red-sensitive cones is 570 nm, green-sensitive cones at 535 nm, rods at 505 nm, and blue-sensitive cones at 445 nm. The EL and ECL blue-green phosphors provide a narrow spectrum well matched to the region of maximum human sensitivity. Hence, surface illumination at low power densities is highly visible

ECL systems offer several economic and societal advantages over traditional lighting. Initial outlay costs for ECL signage is comparable to conventional lighting. For example, the sign in Figure 1 is solar powered. The cost required to run a 15 amp circuit to the sign location (550 ft) would have cost \$6000 whereas the photovoltaic power supply system plus installation was \$5155. For indoor applications, utility power can be used. In some applications, the ECL lifetimes up to 100,000 hours may be possible. Moreover, they provide low maintenance operation – a feature that reduces costs associated with frequent bulb replacement, a particularly important factor for locations that are difficult to access.

Landscape lighting applications (often termed "lightscaping") offer substantial ECL opportunities. Pathway elements like flagstones, step edges, corner markers, etc. can be ECL lighting fixtures which are both beautiful and functional. The strategy is to light the path rather than the path area. The durability of the ECL ceramic-on-steel technology permits rough handling and outdoor exposure without damage. The low power levels and long service life provide an attractive life cycle cost. A low voltage distribution system can be used (typically, 24 Volts at 400 Hz). Entrance signs, exit signs, security warnings, building numbers, and address markers are also part of the lightscaping system.

Many inside nightlight applications (both residential and commercial) are well matched to ECL capabilities. The bedside tray illustrated below consumes less than 0.25 watts of power while providing an appropriate light level for sleeping areas. Relatively low area lighting levels combined with brighter marker lights for steps, controls, information signage, etc. can produce both a safe and efficient nighttime ambiance for both commercial and residential structures.

Vandalism is an unfortunate, but very real, component of lighting system lifecycle cost. The inherently rugged ECL technology offers promise in providing nearly indestructible fixture configurations.

Simple and effective controls represent a critical element in an efficient lighting system. ECL illumination levels are governed by both the drive frequency and voltage. Hence the inverter electronics provide a control point easily adapted to photocells, IR presence sensors, etc. for both on/off and smooth intensity control. Modern inverter designs achieve conversion efficiencies in the 80 to 85% range minimizing the heating load on building cooling systems.

Currently, the plastic EL lamp is the major market competitor of ECL devices. While the flexible plastic EL lamp is preferred in some consumer products (wrist watches, portable monitors, etc.), ECL potentially offers multiple advantages for residential and commercial building applications. Unlike plastic EL lamps that require special encapsulation for mechanical strength, the ECL is inherently strong because of its ceramic and steel structure. In addition, ECLs are inherently more resistant to the diffusion of moisture and oxygen that can degrade phosphor performance. As a result, ECL lamps are well suited for outdoor applications with high environmental stress. ECLs are also particularly well suited for locations that are prone to vandalism (stairways, hallways, public restrooms, subway stations, etc.). Moreover, the technology used to fabricate the ECL is compatible with high-volume, low-cost production.

Light Pollution - “Brighter” is not necessarily “Better”

With regard to building system elements (including the surrounding landscapes), the components of light pollution include:

- 1) **Glare**, blinding human vision and harming visibility
- 2) **Light Trespass**, offending light levels "trespassing" on adjacent property
- 3) **Clutter**, harming esthetic values and enhancing confusion
- 4) **Energy waste**, believed to exceed \$1 billion/yr for external lighting in residential and commercial structures alone
- 5) **Urban sky glow**, endangering mankind's view of the universe.

The rapid growth in nighttime light "pollution" is evident to any observer by simply driving through typical urban, suburban, and rural areas. "More and Brighter" is clearly the prevailing theme with Las Vegas apparently providing the example to emulate. There is almost a competition between businesses for the brightest, most glaring, displays of light without regard to the associated waste of energy resources. The specific issue of urban sky glow has been well articulated by the American Astronomical Society, the International Dark-Sky Association (IDA)[1], and other interest groups. IDA has over 2000 members in 70 countries. The International Lighting Commission (CIE) and many national organizations now have technical committees addressing the issues with reports and recommendations pending. Many lights burn throughout the night both inside and outside our building structures whether needed or not. Safety and security are often the cited reasons for brightly lit areas. Yet transient adaptation of the human eye can limit visibility in less well-lit areas. "Blinding" lights and "dark shadows" are more the rule than the exception creating multiple hiding spots for would-be intruders. In truth, a well lit sign announcing the presence of a security system can be a simple and effective deterrent. Shadowed step areas are especially dangerous in terms of falls and injury. Visible address markers can be a critical time-saving factor for emergency services personnel. The International Dark Sky Association estimates that over one billion dollars per year is wasted in the United States to simply light up the night sky (see IDA Information Sheets 3 and 134).

A practical solution path to light pollution lies in quality lighting systems which enhance the nighttime ambiance rather than attempting to reproduce inappropriate daylight conditions. A powerful design approach is to directly light the surface of objects and information sources which need to be visible, with minimal use of reflected light, using spectra matched to human eye sensitivities. Because the required light levels (and power demands) can be remarkably low, surface light sources and associated fixture design are the critical parameters rather than simple conversion efficiency in terms of lumens/watt of electrical power. Through the use of electroceramiescent lighting systems, substantial energy savings can be realized while enhancing both the environment and the economy. There are no losers in this equation

National Energy Savings

Background

Residential and commercial lighting account for 14 % of the total national energy use. The Department of Energy recognizes the potential for a 50% decrease in lighting energy consumption by the year 2010.[1] To achieve this reduction, advances in lighting systems technology are required including sources, fixtures, and controls as well as a more sophisticated understanding of user needs and preferences. Brighter is not necessarily better! Light "pollution" is a growing problem endangering nighttime ambiance in many dimensions from garish displays of advertising excess to dark sky concerns. Maximum efficiency for building lighting systems will likely require new levels of design sophistication carefully addressing specific user needs with appropriate

discrimination between daylight activities and nighttime requirements/ambiance. Primary variables include increased use of daylight where possible complemented by appropriate lighting levels and systems for nighttime activities. Since many building areas (and surrounding grounds) are lighted at night primarily for ingress and egress, there is a leveraged opportunity to combine low background levels of illumination with highly visible, but non-polluting, information and safety “objects” (controls, general signage, security warnings, stair edges, path markers, hazard markers, etc.). Electroceramesscent lighting technology can be a significant component of such a hybrid system.

Commercial Lighted Signs

Commercial lighted signs represent a specific application opportunity for electroceramesscent systems wherein energy savings are typically greater than 90% (i.e. EC signs consume less than 10% of the power required by fluorescent or incandescent systems). Based on industry surveys, Signs of the Times Magazine [2] reports in the yearly “Electric State of the Industry ” analyses that sales of commercial signage have increased from \$2.3 billion/yr in 1983 to \$5.4 billion/yr in 1999 with approximately half of this amount allocated to illuminated signs. Assuming an average life of 15 years and an average cost of \$1,500/sign, the installed base is on the order of 19 million signs. Assuming an average power consumption of 200 watts per sign for 12 hrs/day, 365 days/yr, the total power consumption is approximately 17 billion KWh per year. Assuming a year 2001 energy cost of \$0.1 per KWh, the current operational cost of these signs (energy component only) is approximately \$1.7 billion per year. Using electroceramesscent technology, this energy cost could be reduced by at least 90% with savings of approximately \$1.5 billion per year (100% market penetration) corresponding to potential energy savings of 15.3 billion KWh (0.17 quads). The cost savings from reduced energy consumption alone would more than repay the sign cost over the expected sign lifetime. When the lower maintenance costs are included for EC signs, the break-even point for sign replacement would be approximately 5-7 years depending upon the labor cost associated with lamp replacement.

Assuming a more realistic market penetration of 25%, EC commercial signage would enjoy a market share of \$625 million/yr in sales with energy savings of 3.8 billion KWh (0.043 quads). Assuming a sales generation rate of \$100k/employee, the EC signage sector would employ 6250 people.

As a point of comparison, the EPA Energy Star program has featured exit signage as a significant national energy savings opportunity. According to EPA [3], there are approximately 100 million exit signs in operation. Early designs used incandescent lamps with a power consumption of approximately 20 watts, 24 hrs/day corresponding to a total energy consumption of 17.5 billion KWh per year . The “Energy Star” objective of 5 watts is leading toward an energy savings of 13 billion KWh/yr (0.14 quads) with an energy cost savings of \$1.3 billion/yr (assuming \$0.1 per KWh). It is interesting to note that commercial illuminated signage offers a similar savings potential; however, practical market penetration limitations certainly support the choice of exit signs as a significant immediate target of opportunity.

6.2 Qualification Testing and Validation Projects

Complete ECL sign assemblies have successfully completed thermal cycle testing over a temperature range from –20 deg. F. to +120 deg F. plus simulated rain exposure including total immersion. MRE has been conducting facility signage and pathway marker lamp testing at the DOE National Renewable Energy Lab (NREL) in Colorado for 3 years.

Demonstration signage is currently in test at Twin Falls State Park in WV. Additional facility signs are being fabricated for installation at the Appalachian Transportation Institute (ATI) in Huntington, WV, and the DOE National Energy Technology Lab (NETL) in Morgantown, WV. Under subcontract with ATI, a pair of “smart” highway information signs will installed on Interstate 64 (see Figure 3). These highway signs respond to inclement weather by dramatically increasing the illumination intensity. In composite, all of these demonstration and test programs are intended to validate the reliability and performance of ECL systems. With reference to Figure 3, a weather sensor (1) commands the illumination level with the signs linked through an RF link (3). Power is provided by a solar panel/battery system (2) and the sign system is linked to a central control point using cellular telephone links (4 and 5).

The validation program will qualify a minimum of seven(7) categories of signs for State and Federal Park applications and a minimum of three(3) categories for highway applications with a typical test sample size of 10 for each major category (i.e., a total of approximately 75 sign systems). The end result will be a catalog of qualified products for MRE to offer for State and National park applications with comprehensive field test data records, testimonials, etc. The highway signage will be pre-qualified through this effort, ready for submittal to a third party test agency for final USDOT qualification. Performance will be monitored and evaluated by third party organizations.

TWIN FALLS ENTRANCE SIGN

Figure 3 - Twin Falls Entrance Sign

Figure 4 - "Smart" Highway Signs

7.0 CONCLUSIONS

All primary objectives were achieved. The analyses of the first generation SSCL materials and processes provided clear explanations for all primary performance characteristics and anomalies. The "Second Generation" ECL product provides performance competitive with plastic EL in outdoor environments. The planned validation program is a critical component of the marketing plan for rapid commercialization. The performance improvements are listed in Table 1 below.

PERFORMANCE COMPARISONS		
Lamp	Gen I	Gen II
1) 1 FT-L GREEN 60 Hz, 120 volts	7 mw/sq. in.	2 mw/sq. in.
2) 7 FT-L GREEN 400 Hz, 150 volts	40 mw/sq.in	5 mw/sq. in.
3) 3 FT-L WHITE 800 Hz, 180 volts	60 mw/sq. in.	20 mw/sq. in
4) 6 FT-L WHITE 800 Hz, 200 volts	NA	30 mw/sq.in

Table 1 - Performance Comparisons

8.0 REFERENCES

- [1] Federal Assistance Solicitation (PS) for “Energy Efficient Building Equipment and Envelope Technologies,” PS No. DE-PS26-99FT40528, dated March 3, 1999.
- [2] “Signs of the Times Magazine”, ST Publications, State of the Industry(SOI) 2000.
- [3] www.yosemite1.epa.gov/estar/consumers.nsf/content/exitsigns.htm, 9/10/2001
- [4] "First Year Progress Summary, Solid-State Ceramic Lighting Project", Principal Authors Wayne Brown and Dr. Doreen Edwards, DOE Award DE-FC26-99FT40631, October 2000.
- [5] "Protective Coatings for Electroceramescent Lighting Panels intended for Highway Signage Applications, Year 1 Final Report", Norton et al, TRP 99005, Nick J. Rahall Appalachian Transportation Institute, Marshall University, September 2001.

APPENDICES

A - MRE Corporate Summary

Meadow River Enterprises, Inc. (MRE) is a cutting-edge provider of conventional and innovative metal fabrication, and Solid-State Electroceramesscent lighting solutions. Since 1987, MRE has researched, developed, designed, manufactured and marketed competitively priced quality products (and services) through cultivated Original Equipment Manufacturer (OEM) channels. With both a short-run and a volume-oriented production facility operating simultaneously, MRE can accommodate a diverse range of client needs in an efficient and timely manner. It is our company's mission to utilize every possible synergistic resource available in order to enhance our product's value and to cultivate long-term customer relationships.

Meadow River's primary facility (22,500 square feet, on 22 acres in Alta, WV) houses a wide array of equipment. A sampling of MRE's production equipment includes: CNC Lasers, CNC Lathes, CNC Milling Machine, NC Brake Press, numerous MIG Welders, Manual Lathes, Milling Machines, Fabrication Stations and Paint Booth.

The MRE Production Team is comprised of highly trained individuals committed to producing durable products designed to exacting engineered specifications. Ongoing training initiatives further insure that all personnel are certified (and current) in their respective fields of expertise.

MRE's Design Team possesses a diverse compliment of talents and skill-sets focused towards providing the client with premium solutions. Economy, efficiency

effectiveness and quality are the core design objectives

MRE AT A GLANCE

Year Established	1987	Full-Time Employees	38
Private Sector Sales	\$2,000,000 (2000)	Certified Technicians	16
Primary Facility	22,500 sq. ft	MIL-45208A Compliant	Yes
Secondary Facility	10,000 sq. ft	ISO 9002 Compliant	In Progress