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LED Technology in Roadway Work Zone Light Emitting Safety Devices

Application Brief I-014

Introduction

The need for a cost effective, power efficient, and dependable light source has prompted the implementation of LED technology in roadway work zone light emitting safety devices. In years preceding 1992, most work zone light emitting safety devices used incandescent lamps. Then during the years 1992 through 1994, the work zone safety industry made a conversion from incandescent lighting to light emitting diode technology as the light source of choice.

The Need for a Dependable, Low Power Light Source

It is imperative that roadway work zone light emitting safety devices be dependable. To ensure the safety of both roadway work zone personnel and the motoring public, light emitting safety devices must be capable of operating for long periods of time without the need for on-going short term maintenance. The constant replacement of burned out incandescent lamps, the need for replacement of low batteries, and continual filling of fuel tanks associated with light emitting devices in roadway work zone areas adds a significant burden to the efforts of roadway engineers and contractors to provide for safety at all times. All of this extra burden dictates the need for a durable, low power replacement light source. This new light source must equal or exceed the light emitting performance provided by incandescent lamps.

LED Technology Has Replaced Incandescent Lamps, Meeting Work Zone Dependability and Low Power Requirements

LED lamp devices have replaced incandescent lamps in roadway work zone light emitting safety devices. The long term reliability of a semiconductor light source has eliminated the need for constant lamp replacement. The light output performance of 1996 vintage LED lamp devices equals or exceeds that of incandescent lamps. The low power consumption of LEDs allows the use of solar energy as the primary power source for driving LED light emitting work zone safety devices, reducing operating costs.

Environmental Benefits of Using LEDs

The use of solar power to drive LEDs makes light emitting work zone safety devices compatible with the environment. The low power consumption of LEDs reduces the need for frequent battery replacement in light emitting work zone safety devices. Batteries are considered to be hazardous waste requiring special disposal procedures. Not having to frequently replace batteries translates into a reduced need for costly environmentally safe landfill disposal areas to dispose of dead batteries. Similarly, eliminating the need for diesel powered electrical generators reduces air pollution from noxious exhaust fumes in work zone areas. Work zone personnel are not exposed to the dangers of handling a volatile fuel. This translates into a distinct financial saving to roadway work zone contractors in the form of reduced premiums for insurance and workman's compensation.

AlInGaP LED Technology

With the advent of the AlInGaP (aluminum indium gallium phosphide) LED technology, LED lamp devices now challenge incandescent lamps in light output performance. Introduced to the market in 1992, this technology has proven to be superior in overall performance to incandescent lamps and has become the light source of choice in the work zone safety lighting industry. Producing an amber color with a dominant wavelength of 590 nanometers (nm) with a light output efficiency equivalent to that of typical amber filtered incandescent lamps at ~10 to 15 lumens/watt, AlInGaP LEDs meet the light output requirements for variable message signs, arrow boards, and barricade warning lights, both flashing and steady burn. With continued development of the AlInGaP LED technology, it is anticipated that significant gains in light output efficiency will be achieved over the next few years, as is shown in Figure 1. Efficiencies should exceed 20 lumens/watt in the amber color range. With these improved LED light output efficiencies, roadway work zone light emitting safety devices will be able to operate at less power with improved performance and better visibility to motorists.

High Light Output Performance

The light output efficiency, luminous output per electrical watt input, of high brightness LED technologies used in traffic management applications has been steadily improving since 1988, as shown in Figure 1. The first high brightness LED technology developed is the 644 nm red TS AlGaAs (aluminum gallium arsenide) used in red LED traffic signals. The light output efficiency of 8 to 10 lumens/watt for this LED technology exceeded that of a red filtered incandescent by a factor of ~3X. Utilization of TS AlGaAs in 12 inch red ball traffic signals reduces the power consumption by a factor of 6 (25 watts for a red LED signal vs. 150 watts for a red incandescent signal).

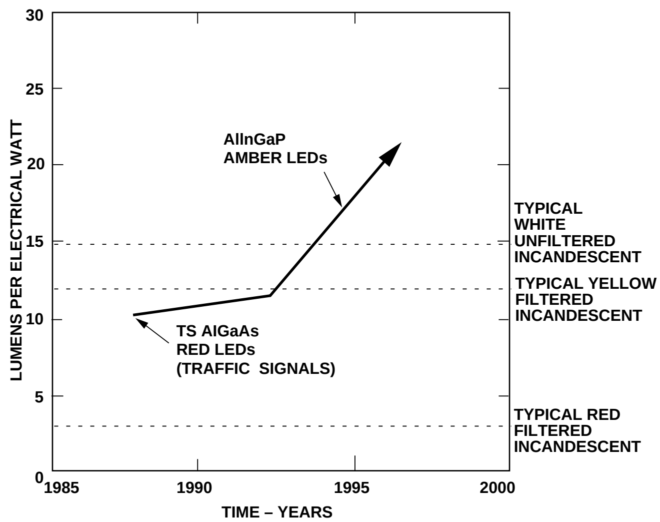

Figure 1. Light Output Improvement History for High Brightness LEDs.

LED Colors

The saturated (pure) colors produced by AlInGaP LEDs do match ITE color requirements in the red, Portland Orange, and amber (yellow) regions as shown in Figure 2. The AlInGaP yellow-green falls outside of any ITE defined color region, but is very close to the color Stark Yellow-Green. InGaN has the capability of producing blue, matching that used on police car lights and blue-green matching that required for traffic signals.

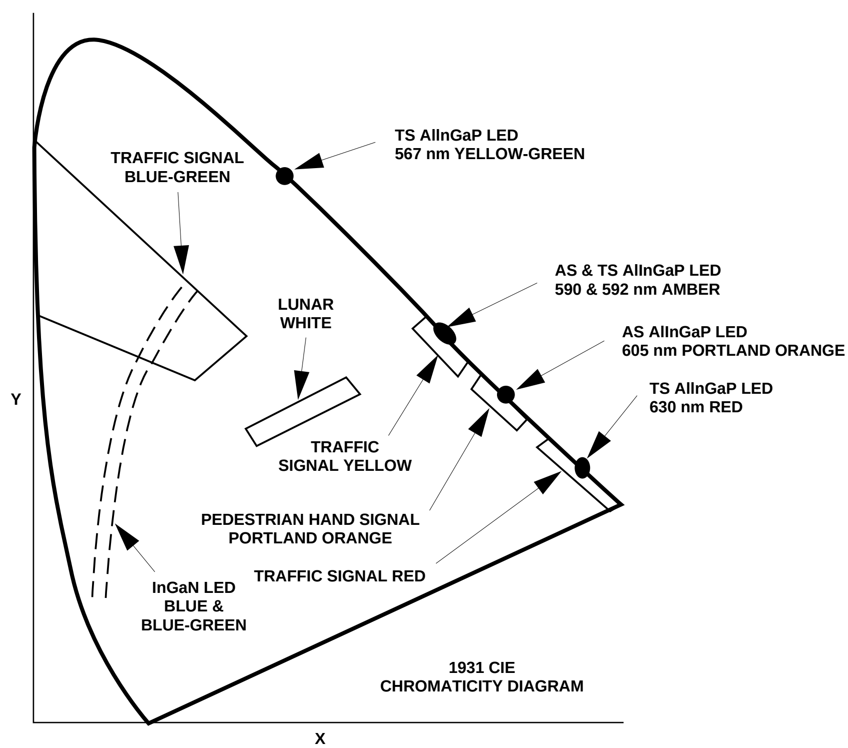

Figure 2. LED Colors with respect to ITE Color Specifications.

T-1 $^3/_4$, Plastic, LED Lamp Configuration

An LED lamp is a solid plastic, solid state device, as shown in Figure 3. The semiconductor LED chip is the actual light emitting element. The LED chip is die attached and wire bonded to a lead frame which is then encapsulated inside a solid epoxy dome lens package. There is no glass envelope, no wire filament, or moving parts associated with this device.

Design Attributes: The T-1$^3/_4$ LED lamp package has the following attributes, designed to ensure the optical performance needed by work zone light emitting safety devices:

- Precisely controlled manufacturing processes to ensure product consistency, device-to-device.
- Precision placement of the LED chip within the lamp package to ensure radiation pattern ($2\theta^1/_2$ viewing angle).
- Newly formulated, proprietary encapsulating epoxy providing increased high temperature performance and improved resilience to moisture absorption. T_{JMAX} LED increased to +130°C, relieving concerns for dependable operation in high ambient temperature locations, such as the U.S. Southwest. Survival in 85°C/85% RH testing exceeds 5000 hours, increasing the operating dependability in high ambient humidity environments, such as the U.S. Southeast.

The T-1$^3/_4$ package configuration provides versatility for design. LED lamps may be grouped into a cluster to form a particular pixel size. LED lamps may also may be

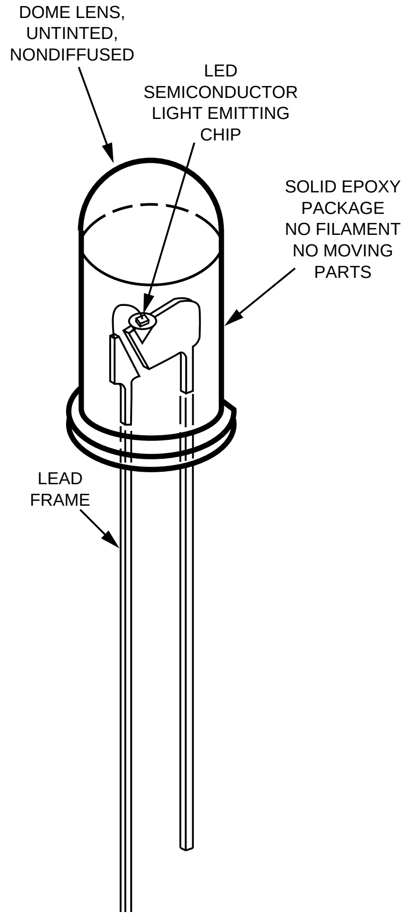

Figure 3. T-1 $^3/_4$, Plastic, LED Lamp Configuration.

used with or without secondary optics to achieve a desired luminance and radiation pattern.

Dependability of LED Devices in Work Zone Light Emitting Safety Devices

Dependability: In work zone environments, LED devices are required to provide a high degree of dependability:

- Operate over long periods of time without need for replacement.
- Withstand high levels of mechanical shock and vibration.
- Operate over the ambient temperature range from -40°C (-40°F) to +71°C (+160°F).
- Withstand weather elements, wind, rain, snow, sand, sunlight.

The T-1$^3/_4$ solid plastic package configuration gives LED lamps their long term dependability in work zone light emitting safety devices.

- Being semiconductor devices, LED lamps do not exhibit a burnout characteristic as do incandescent lamps, eliminating the need for periodic replacement.
- LED lamps, being solid package devices, are mechanically rugged, being able to withstand high levels of mechanical shock and vibration exhibited by the rough environment of work zone areas.
- LED lamp devices are capable of operating from -40°C (-40°F) to +100°C (+212°F), exceeding that required by work zone safety equipment.
- The second generation encapsulating epoxy that forms the lamp dome package has advanced resilience to moisture and contains uv-a and uv-b inhibitors to ensure long term stability in sunlight.

LED Reliability: T-1$^3/_4$ LED lamp devices exhibit a very high degree of long term reliability:

- Mean time before possible catastrophic failure (MTBF) is in excess of 1.5 million hours when operating in high ambient temperatures.
- The statistical average light out-

put degradation for the amber AlInGaP used in work zone light emitting safety devices is projected to be -25% after 100,000 hours of on-time operation. This light output degradation over long periods of time for AlInGaP LEDs is significantly less than for incandescent lamps.

LED Lamp Configurations

The various LED lamp configurations for use in work zone safety light emitting devices are illustrated in Figure 4. All are T-1$^{3}/_{4}$, untinted, nondiffused, plastic lamps utilizing AlInGaP LED technology. The viewing angle, $2\theta^{1}/_{2}$, is that off-axis angle where the intensity is one half the on axis value. The total angle of view out to cut-off is about twice the $2\theta^{1}/_{2}$ value. The specific work zone safety devices into which these LED lamps are used is given in Table 1. Each LED lamp has been designed to meet the specific requirements of each application.

Recommended Drive Current Range for AlInGaP LEDs, 10 mA to 30 mA, to Achieve Best Long Term Light Output Performance

When operating LED devices at different drive currents, there are trade-offs between the required light output for the application and the associated power dissipation and resulting long term light output degradation. Figure 5 shows these trade-offs. As the LED drive current increases, the light output increases proportionally. The LED power dissipation also increases with drive current, resulting in a higher LED junction temperature. Thus, at higher drive currents, heat sinking to control LED junction temperature should be considered in the design.

LED Drive Currents vs. Light Output Degradation: Of special concern is the light output degradation over time. At 10 mA, where light output degradation is low, the light output may provide sunlight viewability for some devices. At a drive current of 20 mA, light output is typically sufficient for sunlight viewability and degradation is a nominal value and not a concern. For the LED drive current of 30 mA, long term light output degradation is projected to be on the order of -25% for AlInGaP after 100,000 hours of on-time operation. This amount of degradation is acceptable for work zone light emitting safety devices. At drive currents greater than 30 mA, the amount of long term light output degradation becomes high as the current increases and may not be acceptable in work zone light emitting safety devices. Therefore, the recommended drive current range for AlInGaP LEDs is 10 mA to 30 mA.

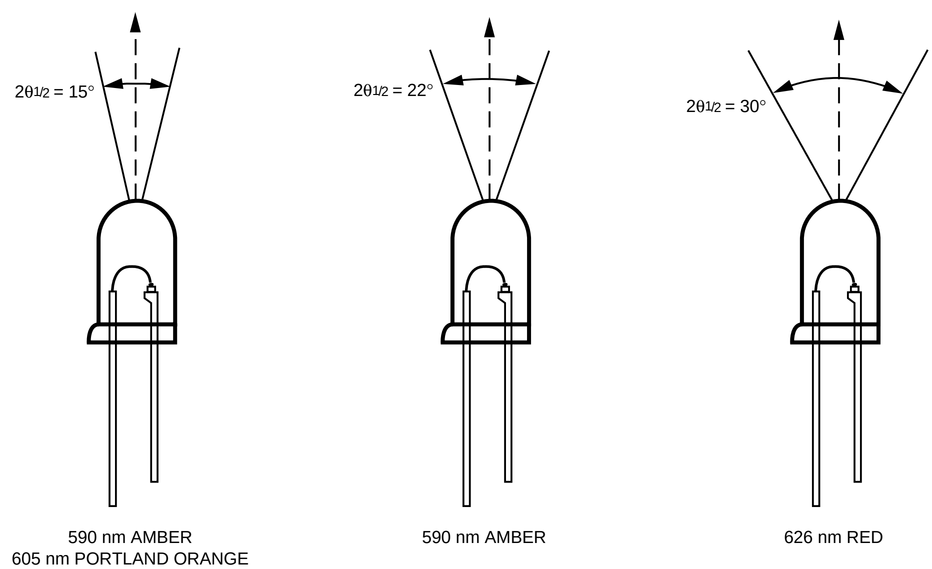

Figure 4. T- 1$^{3}/_{4}$, Plastic LED Lamp Configurations for Work Zone Safety Applications.

Table 1. LED Lamp Viewing Angle and Typical Applications.

LED Lamp $2\theta^{1}/_{2}$ Viewing Angle	AlInGaP LED Color	Safety Device Application
15°	590 nm Amber	Portable VMS Barricade Flashers
15°	605 nm Portland Orange	Pedestrian **HAND** Symbol
22°	590 nm Amber	Portable VMS and Arrow Boards Barricade Flashers
30°	590 nm Amber	Abutment Warning Lights Flashing Caution Lights Traffic Signals, Balls & Arrows
30°	626 nm Red	Traffic Signals, Red Balls and Arrows

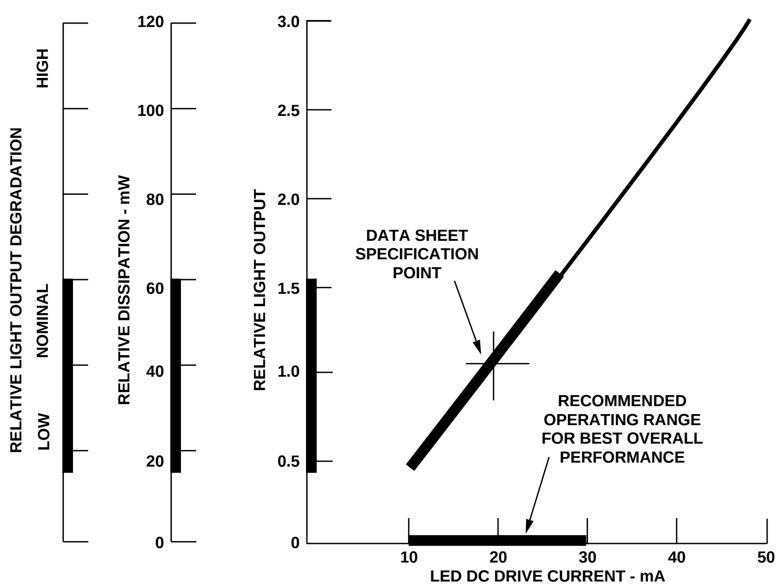

Figure 5. Drive Current Range for AlInGaP LEDs.

LED Work Zone Safety Light Emitting Devices Operate Off Solar Power and Batteries
A major feature of incorporating LEDs into work zone light emitting safety devices is the significant reduction of electrical power consumption over that which is required with the use of incandescent lamps. It has long been known that operating incandescent illuminated devices off solar power could not achieve either sufficient light output or long operation. Also, only limited operational on-time can be achieved from battery powered incandescent illuminated devices. Just the opposite is true in both cases with the use of LED devices.

The following are concept examples of possible LED illuminated work zone safety devices. These conceptual devices are presented to show some of the many lighting possibilities that can be achieved by utilizing LEDs. There is no intent by Hewlett-Packard to represent any actual product that may currently be available with these conceptual examples.

Trailer Mounted Portable Signs: Individual LED pixel elements in trailer mounted portable VMS, composed of between 4 and 12 LED lamps, consume between 120 mW and 480 mW, depending upon LED lamp count and drive current per pixel. (See Figure 6.) This low power consumption is such that these large displays, and portable arrow boards, are now solar powered with battery back-up for nighttime operation. These portable VMS and arrow boards can operate from only battery power, in the absence of sunlight, for approximately 30 days. No diesel generators required.

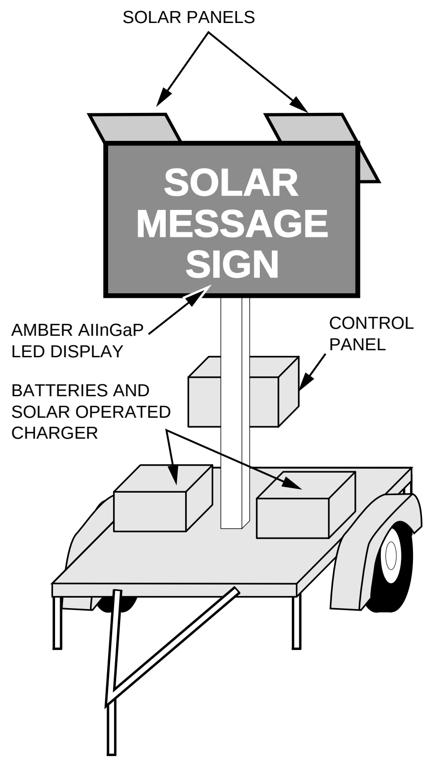

Figure 6. Solar Powered, Trailer Mounted, Portable LED Variable Message Sign, with battery back-up for nighttime use (conceptual drawing).

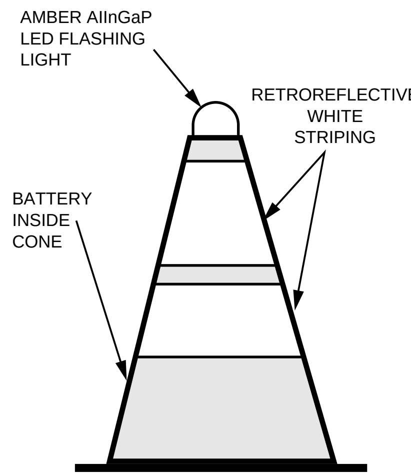

Figure 7. LED Flasher Roadway Marker Cone (conceptual drawing).

LED Flasher Roadway Marker Cones: Battery LED flasher roadway cones using bright amber AlInGaP LEDs is conceptually pictured in Figure 7. The dry battery, located in the base of the cone, can last for weeks without replacement. Now, for added safety, motorists can see at night the flashing amber LED lights on top of the cones, recognizing the marked off roadway section before their headlights illuminate the cones' retroreflective striping.

Portable all LED Traffic Signals: Portable all LED traffic signals, conceptually illustrated in Figure 8, will be the norm in the near future. As with other LED illuminated work zone safety devices, these all LED signals operate off solar and battery power. Not having to rely on local ac power, these signal units can be installed at remote roadway locations, and at critical disaster evacuation roadway locations. Multiple LED traffic signals at various locations can be controlled from a master unit via a microwave data link.

Barricade Warning Lights: Type A, Type B, and Type C LED barricade warning lights, solar powered with batteries, as conceptually illustrated in Figure 9, can last weeks without need for battery replacement. The overall performance and dependability of these LED devices is typically superior to that of their battery operated incandescent equivalents.

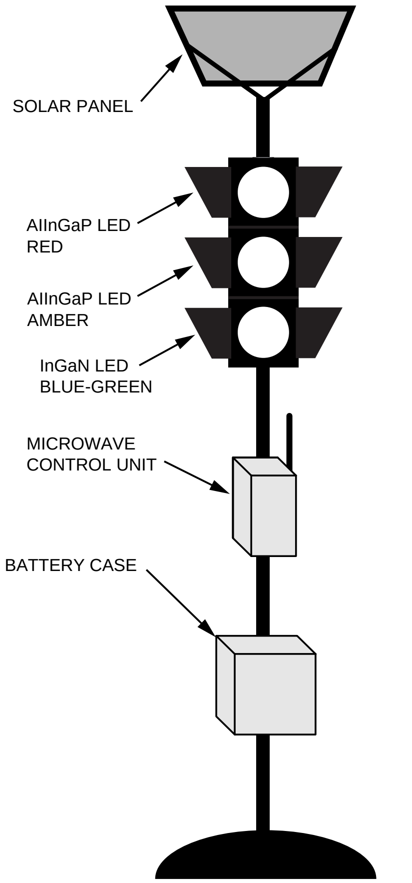

Figure 8. Solar Powered, Portable, All LED Traffic Signal, with Battery Back-Up (conceptual drawing).

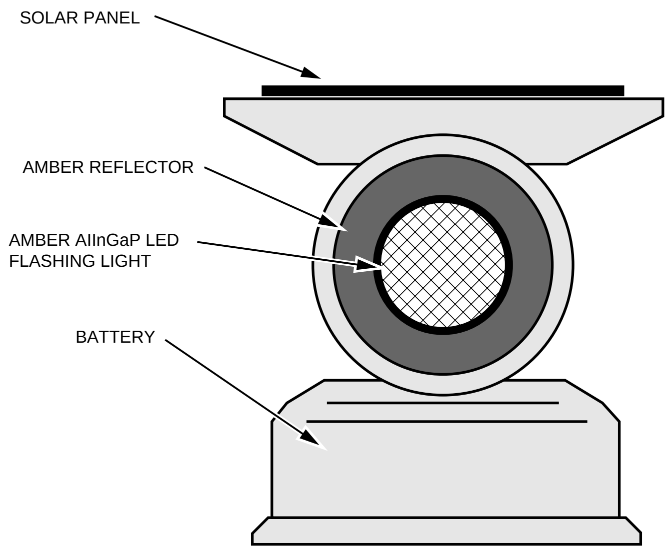

Figure 9. Solar Powered Barricade Lamp, with Battery Back-Up for Night-time Use (conceptual drawing).

Workman LED Traffic Control Flag: Figure 10 illustrates the concept of an electronic LED illuminated workman traffic control flag, solar powered for daytime use and battery powered for nighttime use. The luminance of the TS AlInGaP LEDs equals that of normal traffic signals, giving excellent visibility to approaching motorists in daytime, nighttime, and adverse weather conditions.

Recent Enhancements in LED Technology

Second Generation LED Lamps: New second generation AlInGaP LED lamp devices from Hewlett-Packard are coming on the market. These new lamp devices have enhancements specifically designed to meet the needs of the work zone safety market. Some of the second generation enhancements include:

- New encapsulating epoxy. This new optical grade epoxy has superior resilience to moisture absorption, contains uv-a and uv-b inhibitors, and has a high glass transition temperature (that temperature where the epoxy converts from a lattice structure to an amorphous structure resulting in high stresses on lamp internal parts).
  - Survival in 85°C/85% RH exceeds 5000 hours.
  - T_{JMAX} (LED) raised to +130°C.
- Newly Designed Internal Optics: The internal optics of second generation LED lamps have been designed to ensure a precise optical spatial radiation pattern.
  - The optical axis of each LED lamp is closely aligned with the mechanical axis of the lamp package.
  - The shape of the radiation pattern viewing angles designed for specific applications within the work zone safety market.
  - Precision manufacturing of LED lamp devices to ensure product optical consistency, production lot to production lot.

Future Developments in Green LED Technology

AlInGaP Yellow-Green: Currently under development is a 567 nm yellow-green version of AlInGaP, see Figure 2. The 567 nm yellow-green color is very similar to the color Stark Yellow

Green now under consideration by FHWA for work zone clothing and for pedestrian crosswalk marking. The luminous efficiency is near 8 lumens/watt as indicated in Figure 11. This new yellow-green LED is anticipated to be available in the near future.

InGaN Traffic Signal Blue-Green: The latest LED technology is InGaN (indium gallium nitride), grown on a sapphire substrate. This technology produces colors in the blue region and can produce the traffic signal blue-green color, 498 nm to 508 nm, as shown in Figure 2. The light output efficiency is 10 to 12 lumens/watt, as indicated in Figure 11, thus offering the best possibility for replacing incandescent lamps in green traffic signals. InGaN blue-green LED traffic signals have been shown and have received encouraging acceptance. Some technical development is still necessary with InGaN LED technology to ensure anticipated dependability. InGaN in traffic signal blue-green is currently available in low volume, high cost, engineering sample quantities. However, it is anticipated to be available in high volume quantities at reasonable cost in the foreseeable future.

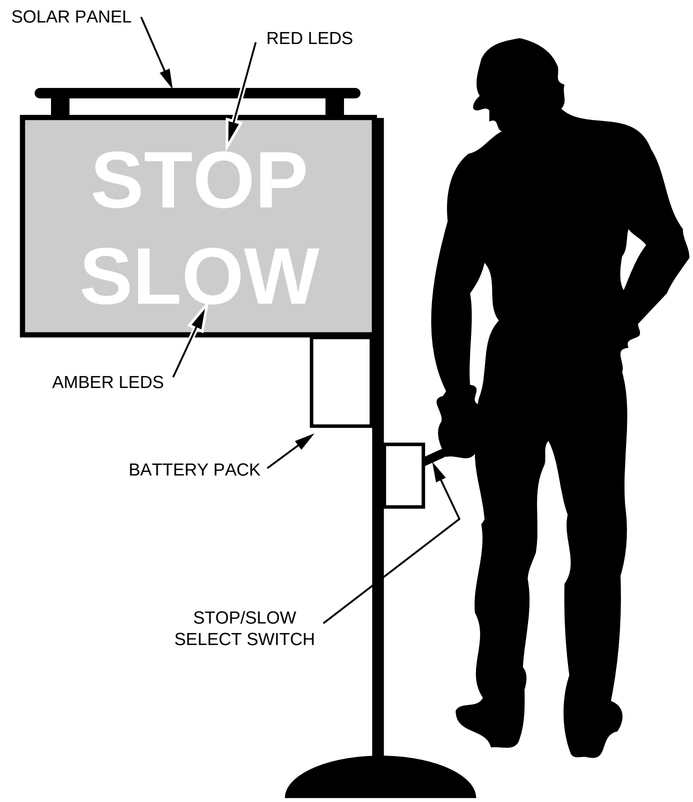

Figure 10. LED Electronic Workman Traffic Control Flag, Solar Powered, with Battery Power for Nighttime Use (conceptual drawing).

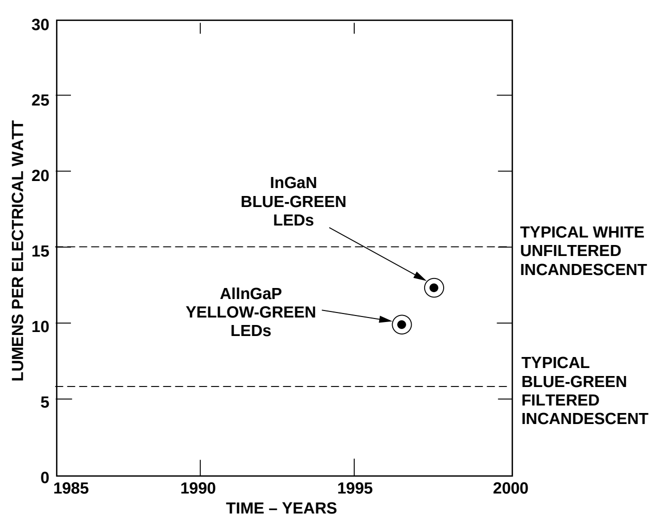

Figure 11. Anticipated Future Green LED Technology Developments.

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