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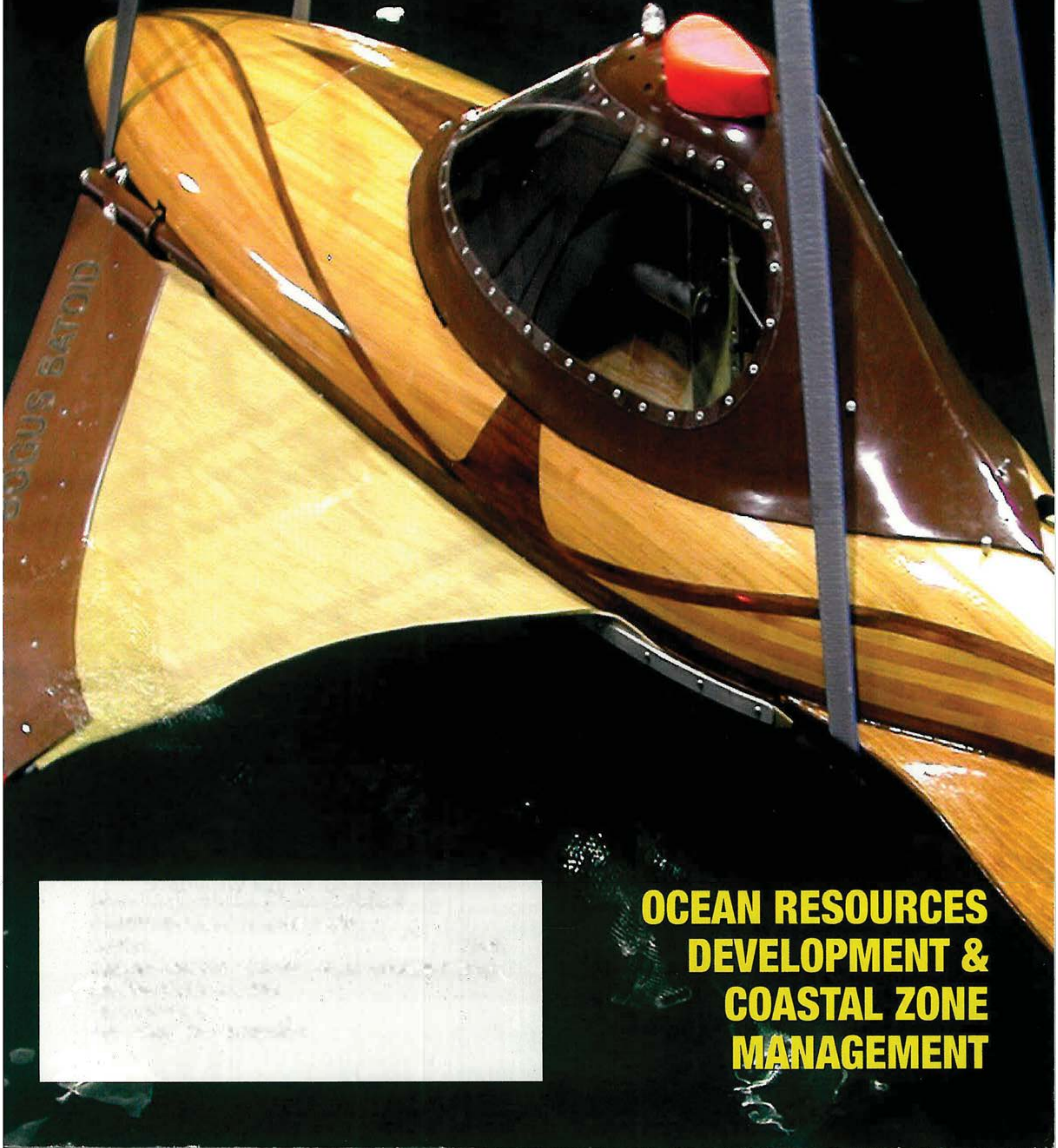

OCEAN RESOURCES DEVELOPMENT & COASTAL ZONE MANAGEMENT

Underwater Applications of High-Power Light-Emitting Diodes

Solid-State Lighting Comes of Age in the Deep Sea as High-Power LEDs Debut on Submersible Alvin Dives

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Just back aboard the research vessel *Atlantis* and still dripping wet, Ken Rand, deep submergence vehicle Alvin support diver, exclaimed, "Wow, those lights are bright!" Alvin had just begun its first 1,600-meter dive outfitted with new high-power light-emitting diode (LED) SeaLites® from DeepSea Power & Light.

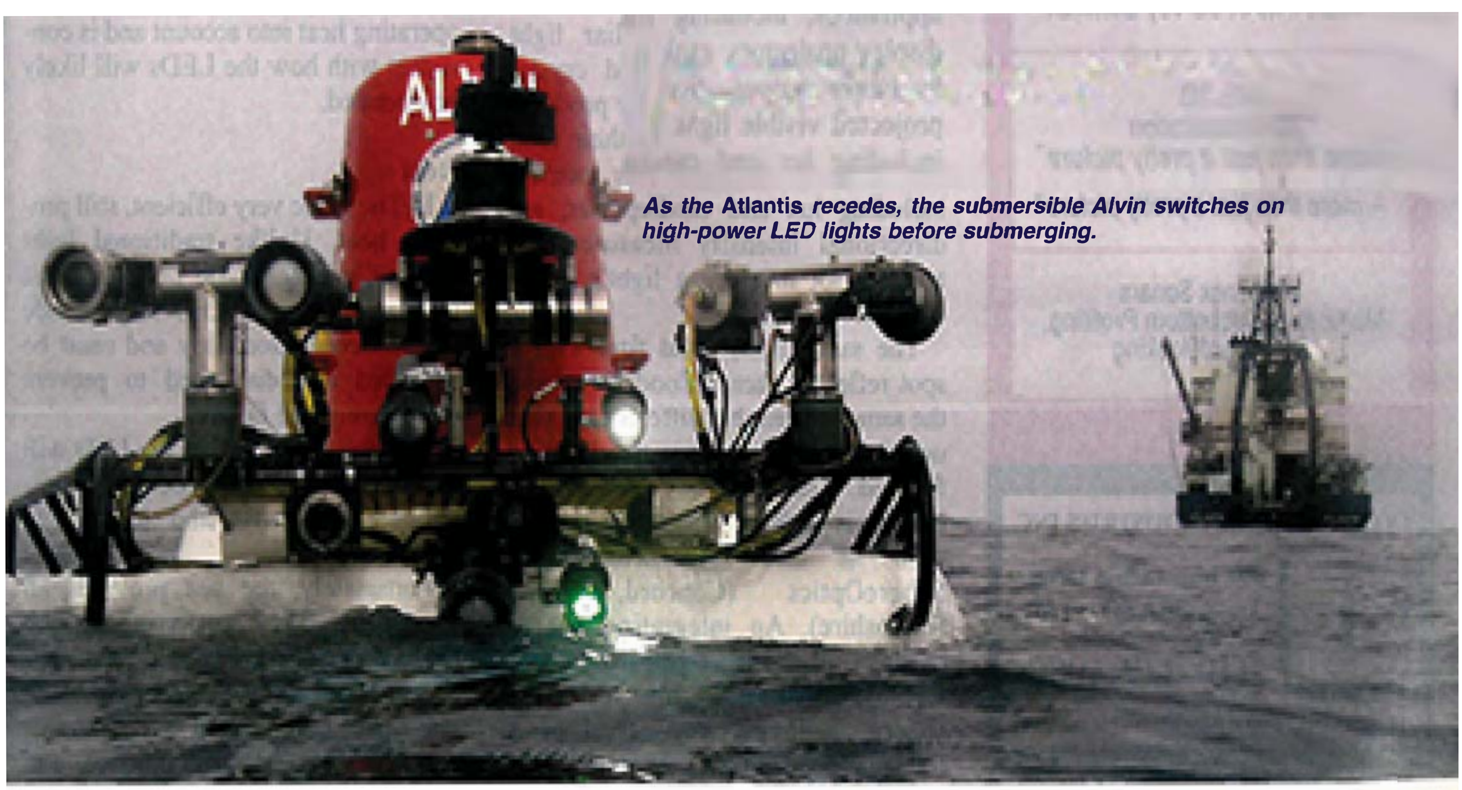
After the first dive, Alvin pilot Sean Kelly said, "I really liked the green LED. It had much less backscatter and greater penetration out front. While I was maneuvering around the bottom, I left the green light on and shut the other lights off."

On the next dive, Alvin pilot Mark Spear said he preferred the white LED for its full-spectrum color.

During the Alvin dives, light bar tests and other performance metrics were taken in order to evaluate the new LED lights.

Solid-state lighting, or LED-based lighting, has seen significant performance improvements recently and is moving from specialty and indication applications, such as traffic signals and flashlights, to general home and business lighting applications. DeepSea Power & Light recently tested its underwater LED SeaLites on Alvin, Woods Hole Oceanographic Institution's (WHOI) manned submersible.

LEDs are quickly catching up to other forms of lighting in terms of total light output and efficiency, and, like all innovations, they offer many significant advantages and some disadvantages. They are very different from traditional light sources and need to be handled with new design methods for optical design, heat management, dimming control and other characteristics. They are worth getting to know. Cree Inc. (Durham, North



As the Atlantis recedes, the submersible Alvin switches on high-power LED lights before submerging.

Carolina), DeepSea Power & Light's choice of LED manufacturer for the Alvin lights, notes their XLamp® LEDs have achieved a 100 percent improvement in performance over the past 17 months. The evolution continues quickly. The day before *Atlantis* left port with Alvin, Cree announced the commercial release of their next-generation white XLamp LED, which provides 25 percent more light using the same amount of electrical power.

How LEDs Work

An LED is a diode consisting of several layers of semiconductor alloy. Light is generated when the LED is forward-biased, and electrical power is driven through a semiconducting alloy where bound electrons capture, then release, electrical energy as a narrow spectrum of monochromatic light. Different doping elements in the semiconducting alloy produce different colors of light. Most white LEDs utilize a single phosphor compound to absorb light emitted in the blue band and re-radiate it as broad-spectrum white light.

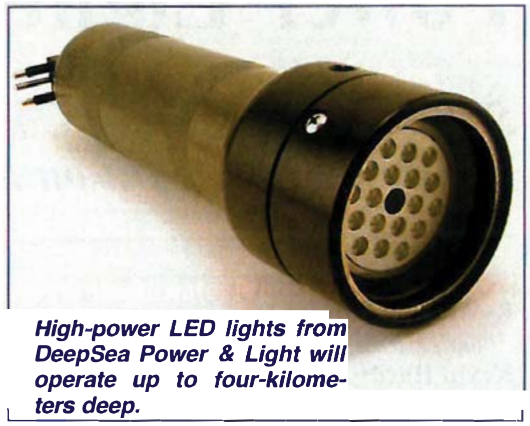
Lumens

The traditional method of classifying light output in electrical watts was made obsolete by the advent of the LED. Today's lights operate with significantly better efficiency, so it is more appropriate to classify a light by its visible energy output, typically measured in lumens. A lumen is a measure of light that can be perceived by the human eye, a human-centric measurement. Other familiar light appliances, including liquid crystal display projectors, rank their products by lumen output—that is, their total projected visible light. Other metrics, including lux and candlepower, are directional intensity measurements and do not measure a light's entire useable output.

The same light, fitted first with a spot reflector, then a flood, will have the same lumens, but different lux values depending on how the light is focused. The best way to measure lumens is with an integrating sphere, such as one manufactured by SphereOptics (Concord, Hampshire). An integrating sphere captures all the light emitted from a fixture inside a highly reflective sphere, removing any effect of a reflector, producing a measurement of total light known as radiant flux—or in visible, human terms—lumens.

Efficacy

Efficacy is a measure of efficiency determined by total light output divided by the amount of electrical power used to produce the light. LEDs are highly energy efficient. The efficacy of the current generation of LEDs is



High-power LED lights from DeepSea Power & Light will operate up to four-kilometers deep.

(Photo courtesy of Tom Kolb of DSPL.)

about six times greater than incandescent light bulbs and on par with all but the highest efficacy fluorescent sources.

There is some disagreement among LED manufacturers on how to measure efficacy. Most prefer to report maximum light output under ideal circumstances, typically optimized with a short electrical pulse and an instantaneous light measurement. Others, including DeepSea Power & Light, prefer to allow the LEDs to reach thermal equilibrium and then report that value. The latter method records less light, but it is a more honest measurement that takes a nominal amount of operating heat into account and is consistent with how the LEDs will likely be operated.

Heat

LEDs, while very efficient, still produce heat. Unlike traditional light sources, which radiate heat, the heat generated from an LED stays inside the semiconductor alloy and must be extracted and dissipated to prevent overheating and failure.

Excessive heat within the LED will cause reduced lumen output, color-temperature shifts and lower life expectancies.

Fortunately, the sea provides an ideal heat sink. Transferring heat to the ocean must be done through the shortest path and fewest thermal barriers. Metal core-printed circuit boards are becoming standard practice, and methods to tie those to the housing challenge designers to keep it simple. The interesting physics of solid-state diffusion and barrier metals await the new explorer.

Drivers

LEDs are best operated as current-driven devices. While voltage remains relatively constant, average current is varied to control light output.

DeepSea Power & Light uses temperature compensation techniques to reduce drive current when LED temperatures exceed a level that would cause damage or degradation to the LEDs.

When operating from alternating current (AC) mains, power factor correction circuitry becomes important, particularly in higher power fixtures. Power efficiency is paramount in reducing heat and minimizing burden on the power source. DeepSea Power & Light offers extremely efficient drivers to support nearly any power source, including wide-range direct current (DC), high-voltage DC and universal AC mains.

Efficiencies exceed 95 percent in some cases, with power factor correction near unity.

Pressure Compensation

Unlike traditional vacuum and gas-based light sources, LEDs are solid-state devices, packaged without voids, making them inherently resistant to pressure affects. DeepSea Power & Light has successfully driven its Cree LED light engines and custom drivers to 20,000 pounds per square inch, while studying the subtle, but very important, issues of phosphor contamination and depressurization effects on LEDs. Satisfactory solutions have been found, though research continues.

Advantages of LEDs

LEDs advantages in underwater applications include ruggedness, longevity, rapid on-off switching without damage, dimming without changing the emitted color, electrical efficiency, pressure tolerance, use of compact reflectors and monochromatic or wide-band color selection. Because LEDs are solid-state devices, there are no shock-sensitive elements to be broken, such as glass envelopes or thin wire filaments. If designed and constructed properly, LED arrays have an extremely long life span. An LED's life is measured as the time it takes for it to reach 70 percent of its initial light output, rather than a complete burnout—a life which can exceed many tens of thousands of hours. It is more likely that an operator will change his LED light engine to upgrade to a higher lumen output than due to failure of an LED string. LED lights come to full power almost instantly and may be dimmed without changing their emitted color, which comes from their semiconductor composition. LEDs produce more lumens per watt than many other lamps, and they operate better at the colder temperatures found in the deep sea. This represents a real advantage to battery-powered submersibles or diver-carried lights. LEDs are pressure-tolerant, allowing smaller, reduced-weight metal housings, unconstrained geometries and lighter frame designs. LEDs intrinsically direct their light forward in a Lambertian distribution, requiring only compact reflectors to redirect edge light. Colors may be selected for a specific application by choosing an appropriate LED. Traditional light filters, which block unwanted colors, also lower light output. High-power LEDs producing narrow-spectrum red, green, blue, ultraviolet, infrared and other colors are currently available. Marine biologists studying animal behaviors or remotely operated vehicle (ROV) pilots working on well heads can now see without being seen, as light in the deep red/near-infrared portion of the spectrum is reportedly not visible to deepwater animals, who have narrowed their sensitivity through natural selection to favor bioluminescent blue-green. LEDs have lower maintenance costs, and increased integration of circuits is improving reliability.

Disadvantages of LEDs

Some disadvantages of LEDs include thermal management, driver electronics and initial cost. The leading cause of premature failure of LEDs is excess heat, so a good design will solve that problem first. LED drivers require knowledge of magnetic core inductors, and component tradeoffs for pressure-compensated circuits must be made. Electronics are sensitive to electrostatic discharge and reverse breakdown voltages if not properly protected. LEDs and their driver circuits may cost more up front than traditional filament or gas discharge lamps of equal lumen output, but, as technology improves, the costs are coming down.

Future Directions

DeepSea Power & Light has a number of future LED projects working their way through research and development, including high-power "bottle cap" mini-lights for mini-ROVs, diver helmet lights and flat-panel light fixtures. One day, panels of LED lights may surround a submersible or ROV, and the vehicle pilot will be able to swivel a camera while sequential panels illuminate a sector, following the camera's motion. A submersible, maintaining constant course, depth and speed, will be able to pass a hydrothermal chimney, filming it with constant illumination as the active vent approaches, passes and recedes from view.

Other emerging topside marine applications of LEDs include use on oil platforms, ships and buoys for safety, general lighting and survival systems. LEDs are well-suited for unattended operation, battery back-up or hazardous environments.

Conclusions

LED lights will create new opportunities for manned and unmanned vehicle and instrument designers. No longer constrained by circles, spheres or cylinders, designers can create hydrodynamic shapes and incorporate LEDs, which are able to survive even the crushing pressures of deep-ocean trenches, in a freeform manner. Still, not all lights can be replaced by LEDs, at least not yet.

Acknowledgements

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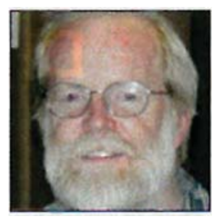

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