what is sometimes considered the ultimate lighting source: one nearly twice as efficient as fluorescent lamps but with half the life ownership cost.

One outstanding challenge is filling the spectral hole in the yellow-green region, within which light emission efficiency becomes very low. At Sandia and at many other laboratories, there is intense interest in studying the high-indium-content InGaN alloys that show the most promise for filling that hole.

**Purple/UV lasers.** Lasers for optical storage gradually will migrate to the purple and the near-UV because shorter wavelengths enable greater areal bit densities. Purple GaN-based lasers with the necessary performance characteristics are poised to power the coming generation of high-density DVDs. A major challenge, further into the future, will be the development of UV lasers suitable for a subsequent generation of ultrahigh-density DVDs.

**UV LEDs.** Monochromatic UV LEDs are much less mature than their visible counterparts, but they also are making rapid progress. Some of their envisioned applications are fluorescence-based bioagent detection and monetary-note verification, purification of microbe-contaminated water, nonline-of-sight covert communications, materials curing (e.g., inks, epoxies and adhesives) for dentistry and other uses, and medical/cosmetic (e.g., acne) skin treatments.

For some of these applications, shorter wavelengths are preferable. Sandia and other laboratories, sponsored by a Defense Advanced Research Projects Agency program, recently demonstrated milliwatt continuous-wave power levels at wavelengths as short as 276 nm (Figure 2). However, an outstanding challenge for these technologies is understanding and controlling the high-aluminum-content AlGaN alloys that show the most promise for such devices.

Meet the authors

Jeff Tsao (jytsao@sandia.gov), Mary Crawford (mhcrawf@sandia.gov) and Jess Wilcoxon (jpwilco@sandia.gov) are members of the technical staff, and Jerry Simmons (jsimmon@sandia.gov) is solid-state lighting program manager, at Sandia National Laboratories in Albuquerque, N.M.

---

**Single-Frequency Fiber Lasers**

by Patrick L. Edsell, NP Photonics Inc.

Optoelectronics and fiber optics technology experienced significant advances in the 1990s, driven largely by well-funded innovation in the telecommunications, semiconductor and consumer electronics sectors. Although some of these sectors have since lost momentum, the trickle-down effect for other photonic applications markets has continued and, in some cases, accelerated. Fiber optic sensors, for example, have achieved enhanced performance by integrating improvements in fiber, laser and photodetector technology. At the same time, the relative cost of such devices has come down as a result of advances in optoelectronics manufacturing methods.

In recent years, factors such as escalating demand for increased security, the need for higher-performance military systems and the difficulty in finding new oil reserves have resulted in a demand for better sensing systems. One response to this has been the development of optical fiber sensing technology.

In comparison with conventional
sensing technologies, fiber-based sensors are lightweight, compact and easily multiplexed; are resistant to hazardous environments, electromagnetic interference and chemical corrosion; require no electrical power at the sensing point; can distribute sensing over very long distances; and are producible at relatively low cost because of the use of readily available telecommunications components. The result is large, fast-growing optoelectronic technologies today. The recent availability of distributed sensors based on optical frequency-modulated continuous-wave sources, today's seismic exploration techniques lead to the extraction of perhaps only 30 percent of the petroleum in a given oil field. Improved exploration techniques, based on optical sensing, are capable of raising that yield to 70 percent. What's more, the cost of an optical sensing system is much lower than the alternative solutions.

Additionally, optical sensing systems can improve the measurement of pressure and temperature in oil wells and in oil and gas pipelines. There are more than 880,000 oil wells, and 80,000 new wells are drilled every year. Pressure and temperature in these wells is measured with electronic monitoring systems that require power at the sensing point and expensive components, requirements that could be eliminated through the use of fiber sensors.

Moreover, there are more than 2 million miles of oil and gas pipelines in North America and more than 5 million miles worldwide. Inspectors driving or flying along the pipelines monitor conditions almost entirely visually. This is very costly and does not provide the opportunity to identify many potential problems before they occur. A distributed optical sensing system could measure both temperature and strain in more than 100 miles of pipeline in real time, thus identifying both existing and potential problems.

Finally, a market opportunity exists to improve high-voltage power line monitoring. There are approximately 200,000 miles of high-voltage power lines in the US. The Electric Power Research Institute estimates that billions of

Searching for undersea oil fields in the North Sea, a ship tows an array of fiber optic acoustic sensors. An acoustic transmitter on the ship’s keel beams sound waves downward, and the fiber optic sensors monitor the signal reflected from the ocean floor.
dollars of electrical capacity is lost every year in the US alone as a result of the inability to accurately measure the strain and temperature on these lines. A distributed optical sensing system could measure temperature within 1 °C and strain within $10^{-6}$ in more than 100 miles of power line in real time.

Research and development. Besides the sensing markets, research and development institutes, such as universities and government agencies, are increasingly demanding sources that feature longer coherence lengths and lower phase noise. Universities and research labs require high-power fiber lasers for a variety of applications and across a number of departments, including in electrical engineering, physics, and lasers and optics.

Meet the author

Patrick L. Edsell is president and CEO of NP Photonics Inc. in Tucson, Ariz.; e-mail: pedsell@npPhotonics.com.