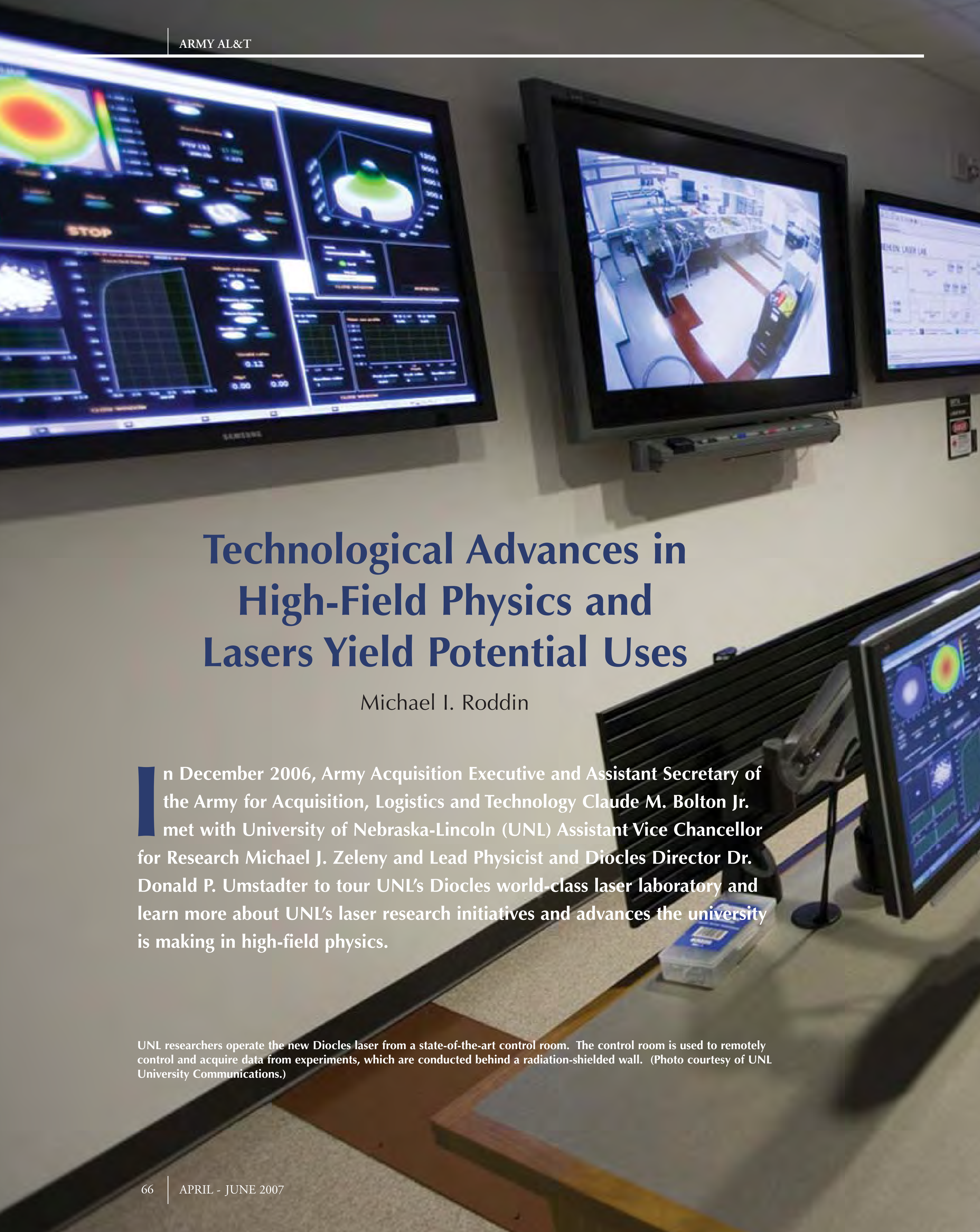
Technological Advances in High-Field Physics and Lasers Yield Potential Uses

Michael I. Roddin

In December 2006, Army Acquisition Executive and Assistant Secretary of the Army for Acquisition, Logistics and Technology Claude M. Bolton Jr. met with University of Nebraska-Lincoln (UNL) Assistant Vice Chancellor for Research Michael J. Zeleny and Lead Physicist and Diocles Director Dr. Donald P. Umstadter to tour UNL's Diocles world-class laser laboratory and learn more about UNL's laser research initiatives and advances the university is making in high-field physics.



UNL researchers operate the new Diocles laser from a state-of-the-art control room. The control room is used to remotely control and acquire data from experiments, which are conducted behind a radiation-shielded wall. (Photo courtesy of UNL University Communications.)

Unveiled in August 2006, Diocles is the latest in a new generation of compact lasers that help researchers produce very brief pulses of extremely intense light. Known as femtosecond optical pulses, they are employed through an ultra-high-intensity laser system that helps scientists study the interactions of light with matter at the highest attainable field strengths. UNL's Diocles has the highest combination of peak-power densities and repetition rates of any laser in the United States, delivering 100 Terawatts at 10 Hertz.

When focused, Diocles is capable of directly increasing an electron's mass relativistically by 20 times.

This latest advance in high-field physics and laser research enables UNL scientists to generate the same level of intense light (in the form of X-rays) in a room-sized configuration that formerly could only be produced by a huge synchrotron accelerator more than a mile in circumference. What does this mean in lay terms? UNL Diocles Director Umstadter says "We can create a tiny 'sun' in the laboratory at the focus of the laser." If this is reminiscent of the nexus where science and science fiction converge, you're not far off, especially if you are a Marvel® Comics Spiderman or Doc Ock fan and remember the 2004 Spiderman 2 movie.

High-Field Science

Physics, traditionally referred to as the science of matter and energy and of interactions between the two, attempts to measure the physical properties,

UNL Diocles Director Dr. Donald P. Umstadter (left) orients Army Acquisition Executive Claude M. Bolton Jr. to the university's ongoing high-field science and laser research prior to a Diocles lab demonstration. (Photo courtesy of UNL University Communications.)

interactions, processes or laws that scientists encounter as they study natural or material world phenomena. High-field science physics is based on the creation of extremely high peak-power levels by squeezing pulses with modest energy levels into ultra-short time frames. When focused, these pulses create electric field strengths rivaling those that bind the innermost electrons of an atom to its nucleus.

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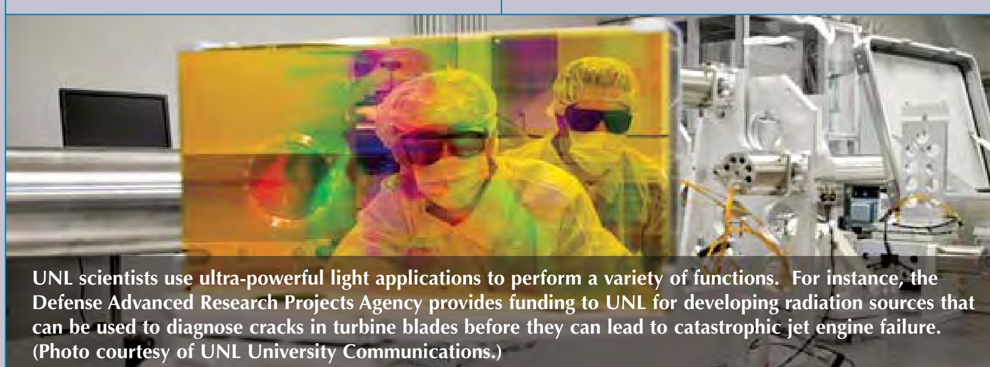
Umstadter and his research team are pioneering this relatively new physics research endeavor called high-field science. Their studies involve the nonlinear optics of ultra-high-intensity lasers interacting with plasmas, also known as ionized gas. The extreme light created by the new laser is enabling applied scientific exploration into applications for advanced radiation sources and particle accelerators.

Moving forward, researchers don't know the depth yet of what can be discovered, because the interaction of light with electrons is highly nonlinear at high intensities and new physical regimes can only be entered at high photon energies. However, scientific expectations are high that the UNL laser research studies of electron correlations in atoms and molecules will unlock new knowledge that will lead to specific commercial and industrial applications in the very near future. Scientists contend that the understanding of electron correlations is vital to modern technology. Superconductors, quantum computers and novel nanomaterials are based on the unusual properties of electron correlations.

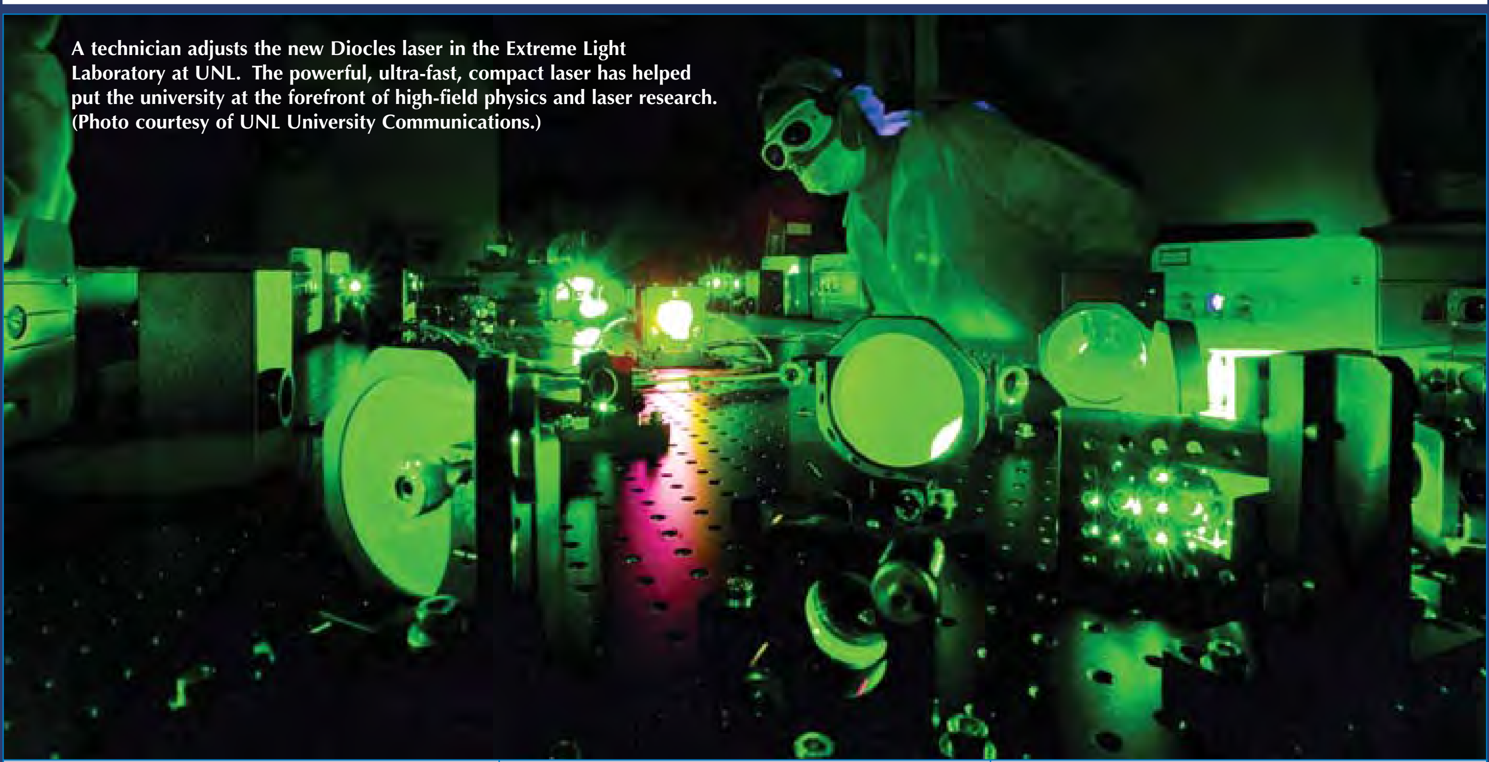
Diocles Laser Research

Named for inventor Diocles, who is credited with inventing the first parabolic reflector in 200 B.C., the laboratory uses this device as a focusing element to increase the intensity of light for experimentation purposes. As Umstadter explains the process, Diocles begins with a modest amount of energy from a short pulse, then stretches the pulse and sends it through a series of amplifiers and titanium sapphire crystals to pump up its power. What makes Diocles capable of delivering such high power is a compression stage, where the stretched, amplified pulse is compressed back into a very short, extremely powerful pulse. This process prevents damage to the amplifiers and allows the powerful light beam to hit a parabolic reflector that focuses its power to extreme intensities.

UNL officials purport that the focused Diocles laser light is the strongest produced on Earth, creating conditions only found in stars like the sun. Accordingly, any material subjected to such conditions becomes heated to extreme temperatures and pressures, and



UNL scientists use ultra-powerful light applications to perform a variety of functions. For instance, the Defense Advanced Research Projects Agency provides funding to UNL for developing radiation sources that can be used to diagnose cracks in turbine blades before they can lead to catastrophic jet engine failure. (Photo courtesy of UNL University Communications.)

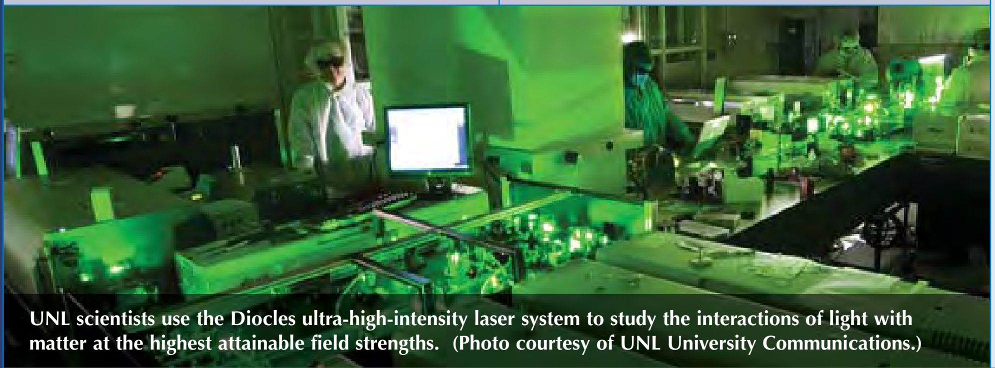


A technician adjusts the new Diocles laser in the Extreme Light Laboratory at UNL. The powerful, ultra-fast, compact laser has helped put the university at the forefront of high-field physics and laser research. (Photo courtesy of UNL University Communications.)

converts the material to the fourth state of matter — plasma. Umstadter's research team uses Diocles to study, under highly controlled conditions, the interactions of light with the hottest fire ever produced in a laboratory setting.

Umstadter is confident that the Diocles laser has the potential for reaching the highest light intensity ever produced by any laser in the world. He contends that Diocles' compact, ultrafast, high-intensity laser can produce more power than 100,000 Hoover Dams in bursts lasting only 30 billionths of one millionth of a second. "When you focus the laser to its highest intensity, you are creating conditions that have never been produced on Earth," Umstadter remarked. "In fact, we can produce pressures that are greater than those at the core of the sun."

Umstadter and his research group are confident that such extreme conditions are likely to lead to new scientific discoveries and, eventually, to new technologies and applications in the science, medical, industrial/manufacturing, defense and security sectors. For example, Diocles produces gamma rays (X-rays) that can "see through" 4-inch-thick steel to detect bomb or nuclear material hidden in cargo containers, or help engineers pinpoint hairline fractures in jet turbine engines and bridge and building infrastructures. Because lasers are small and relatively inexpensive, the medical community could potentially use this laser technology as a proton source for cutting-edge cancer therapy. Obviously, the lessons learned from future UNL studies could benefit ongoing Department of the Army laser research studies and experimentation at the Army's labs. Ultimately, Umstadter hopes to discover what happens to matter when it interacts with light at its most intense state. The Diocles laser is the best way to produce such extreme light, and he hopes his team's research initiatives will raise high-field physics and laser research to the next level.



UNL scientists use the Diocles ultra-high-intensity laser system to study the interactions of light with matter at the highest attainable field strengths. (Photo courtesy of UNL University Communications.)

MICHAEL I. RODDIN is the U.S. Army Acquisition Support Center Strategic Communications Director and *Army AL&T* Magazine Editor-in-Chief. He has B.S. degrees in English and journalism from the University of Maine and an M.A. in marketing from the University of Southern California. Roddin is a former Army Advertising Program Manager and three-time Army Keith L. Ware Journalism Award recipient. In 2005, he was selected by the Secretary of the Army for Editor-of-the-Year Honors.