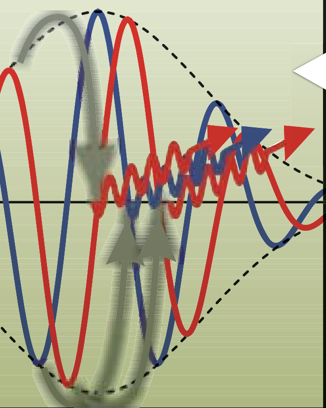

Few-cycle system isolates attosecond pulse PAGE 75

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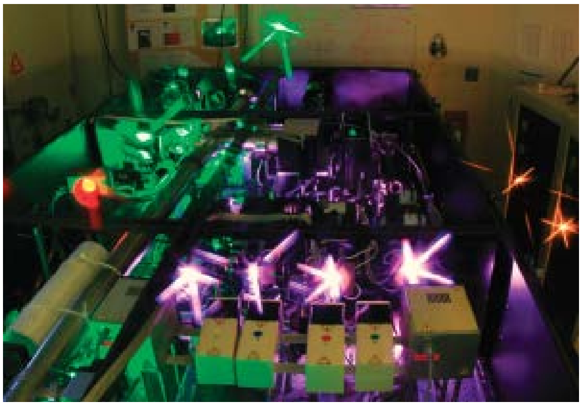
ULTRAFAST LASERS

Michigan group achieves laser intensity record

By adding a booster amplifier to their 50 TW Hercules laser, researchers at the University of Michigan (UM; Ann Arbor, MI) have pushed its peak power to 300 TW—the highest ever achieved for a repetitively pulsed laser. The team also focused the 30 fs pulses to an intensity of 2×10^{22} W/cm^2, the highest ever recorded from a laser.



With the help of its new booster amplifier the Hercules Ti:sapphire laser at the University of Michigan's Department of Electrical Engineering and Computer Science (EECS) produces 300 TW pulses—the highest ever achieved for a repetitively pulsed laser—with a repetition rate of 0.1 Hz. (*Courtesy of University of Michigan/Anatoly Maksimchuk*)

"I don't know of another place in the universe that would have this intensity of light," said Karl Krusheinck, one of the researchers and coauthor of a report in *Optics Express*.[1]

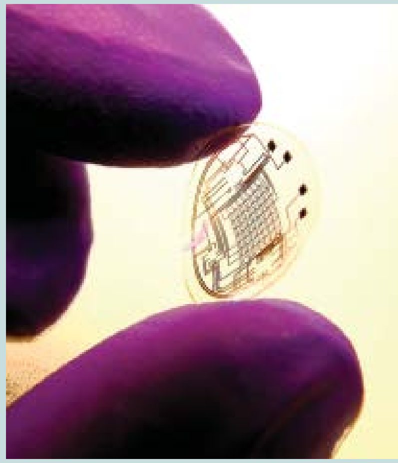
The Lawrence Livermore National Laboratory (Livermore, CA) produced the first petawatt pulses a decade ago with chirped-pulse amplification, and other laboratories have followed (see www.laserfocusworld.com/articles/266389). But those systems are limited to single shots because they use glass amplifiers, which dissipate waste heat slowly. Hercules uses Ti:sapphire amplifiers, with much better heat dissipation that allows a 0.1 Hz repetition rate imposed by the glass pump lasers, says coauthor Victor Yanovsky, who added that diode pumping of solid-state lasers might yield 100 J pulses at 10 Hz (see figure).

In 2004 Yanovsky generated peak powers of 45 TW from Hercules, and focused pulses to a then-record intensity of 10^{22} W/cm^2.[2] After a regenerative Ti:sapphire amplifier boosted seed pulses to 40 mJ, the output was directed to a cryogenically cooled four-pass amplifier followed by a final two-pulse amplifier. A deformable mirror corrected wavefront distortion, and an *f*/0.6 off-axis parabolic mirror focused the beam to a 0.8 μm spot, with peak intensity of 10^{22} W/cm^2.

However, amplified spontaneous emission from the system posed a problem. Amplifiers normally produce a prepulse of amplified spontaneous emission lasting around a nanosecond, which Yanovsky says is "forever" on the timescale of a femtosecond pulse. That prepulse is only about 10^{-6} or 10^{-7} the power of the femtosecond pulse, but when the system optics focus the main pulse to an intensity of 10^{22} W/cm^2 the prepulse is powerful enough to destroy the target before the main pulse reaches it. To overcome that problem, Yanovsky two years ago used a technique called cross-polarized wave generation to reduce amplified spontaneous emission to a level only 10^{-11} of the femtosecond pulse.[3]

Contact lens could create virtual display

Researchers at the University of Washington (Seattle, WA) have successfully embedded optoelectronic devices into a biocompatible contact lens. This achievement is a significant step toward enabling virtual head-up displays within the human eye, delivering visual aids to help vision-impaired individuals, or for incorporating biosensors directly on the surface of the eye, among many other possible applications.[1] "Looking through a completed lens, you would see what the display is generating superimposed on the world outside," said Babak Parviz, an assistant professor of electrical engineering. "This is a very small step toward that goal, but I think it's extremely promising."



Electronic circuits and micro light-emitting diodes (LEDs) have successfully been integrated into biocompatible contact lenses that could be used as virtual head-up displays, or as biosensors for monitoring glucose and blood oxygen levels, for example. (*Courtesy of University of Washington*)

Integrating the devices within the contact lens begins with a 100-μm-thick polyethylene terephthalate (PET) substrate that is used as a template for patterned electrical interconnects and later,

Pumping up the pulse power

Now his group has added a two-pass Ti:sapphire booster amplifier that pumps up the femtosecond pulse power by a factor of six at 0.1 Hz, generating 17 J pulses that, after compression, have peak power of 300 TW and a pulse width of 30 fs at a nominal center wavelength of 810 nm. Focusing those pulses onto a target with a *f*/1.0 parabolic mirror gives peak intensity of 2×10^{22} W/cm^2. Yanovsky explained that they chose not to use the *f*/0.6 lens because its focal length is so short that something is likely to obstruct the output before it reaches the target. If the technique can be extended to the shorter-focus lens, power density should reach 5×10^{22} W/cm^2.

That intensity is close to the level of 10^{23} to 10^{24} W/cm^2 where interesting new physics is expected. Those power densities should produce radiation reaction effects that affect electron motion, offering a test of electrodynamic models that treat electrons as points. A more practical application of such intensities would be to accelerate protons or ions for cancer therapy. Penetrating the body requires electron energies of about 200 MeV, which now can only be achieved with expensive particle accelerators. Current laser acceleration is limited to about 50 MeV—too low to make ions penetrate the body, but higher laser intensities could boost electron energies to the required 200 MeV range.

It won't be easy to crank power up to that range. "We are pretty much close to the limit on the focal spot," says Yanovsky; there is no room to go to mirrors faster than *f*/0.6 at 800 nm. Pulses might be squeezed down to 10 fs, which could yield up to a factor of three increase in peak power, but that's about the limit. Building a bigger laser in principle could yield as much pulse energy as you could afford, but reaching an energy sufficient to generate 100 pW would cost at least $100 million.

The ultimate pulse intensity would be about 10^{29} W/cm^2, Yanovsky says, at which theory predicts the laser beam would create electron-positron pairs from a vacuum. Intensities beyond that could not propagate because pair production would drain their energy. The universe hasn't seen those conditions since the Big Bang, but we're only a factor of several million from that threshold.

Jeff Hecht

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1. V. Yanovsky et al., *Optics Express 16*, 2109 (Feb. 4, 2008)
2. S.-W. Bahk et al., *Optics Lett. 29*, 2837 (Dec. 15, 2004)
3. V. Chvykov et al., *Optics Lett. 31*, 1456 (May 15, 2006).

optoelectronic devices such as light-emitting diodes (LEDs). The films are cut with a CO_2 laser into standard 4 in. wafers for use in standard microfabrication equipment.

To create the electronic circuits, standard photolithography, metallization, and lift-off steps are performed on the resist-patterned wafers. The wafers are then baked and cut into contact-lens shapes again by a CO_2 laser.

Demonstration of the incorporation of a representative optoelectronic component was accomplished with a red-emission micro-LED. Compound semiconductor multilayer structures were grown separately from the contact lens using metal organic chemical-vapor deposition to create circular LED structures with approximate 320 µm diameters. Building the active LED structures on a sacrificial aluminum arsenide layer allows them to be easily removed with a hydrofluoric acid etch and placed on the contact lenses as individual elements.

Using a self-assembly process, alloy bumps are placed on particular locations or assembly sites on the PET wafer and the LED microdevices are flowed in solution over the wafer and attach to the assembly sites. The LED devices have *n* and *p* contacts on the same side of the LED for activation by the electronic template patterned on the wafer. A final heating step melts and joins the LEDs to the template metal interconnects.

Finally, the contact lenses with optoelectronic elements are encapsulated with a polymethylmethacrylate (PMMA) coating to make them biocompatible with eye tissue. The lenses are then placed in an aluminum mold and baked to obtain the curvature of a contact lens (see figure).

The lenses were successfully tested on rabbits (without LED structures), and