



Ray gun made from glass insulator disks from high voltage cables.

Half a Century of *Laser Weapons*

Jeff Hecht

Even before the laser was invented, science fiction writers saw rich potential in the use of light-beam “death rays” as powerful tools of destruction. But the real history of directed-energy weapons in the United States has been fraught with political and technical challenges and setbacks.

Fifty years ago, two physicists walked into the U.S. Advanced Research Projects Agency with just the kind of far-out idea that ARPA wanted. Gordon Gould and Lawrence Goldmuntz had a plan to generate a beam of coherent light. Gould called it a laser.

The time was ripe. Five months after the October 1957 *Sputnik* launch, the Pentagon had created ARPA to handle the risky projects that military research bureaucrats instinctively avoided. In May, ARPA director Roy Johnson told Congress that his agency's work "might lead to a death ray. That would be the weapon of tomorrow," a step beyond the hydrogen bomb. No such weapon was in development, he admitted, but, he said, "we have to keep our mind open to everything."

The laser had come to the right place. Many years later, Gould told me, "Ray guns and so on were part of science fiction, but somebody actually proposing to build this thing? And he has theoretical grounds for believing it's going to work? Wow! That set them off, and, those colonels, they were just too eager to believe."

Seeking the ultimate weapon

Optical weapons may have entered the arms race in ancient times, when Archimedes supposedly used mirrors to focus sunlight onto Roman ships besieging the Greek city of Syracuse, setting them afire.

We don't know what truth lies behind the ancient tale; the oldest existing accounts were written in the 12th century. We do know that Syracuse fell in 212 B.C.E., when, according to another legend, a Roman soldier killed Archimedes. Yet the ancients did know about burning mirrors. Greek mathematician and philosopher Diocles described focusing sunlight with parabolic mirrors in a book titled *On Burning Mirrors*, says Lawrence M. Kaplan, historian for the U.S. Missile Defense Agency. But whether or not Archimedes burned Roman ships, a series of modern experiments, most recently conducted by MIT students in 2005, have shown that it's possible to

The WAR of the WORLDS By H. G. Wells

Author of "Under the Knife," "The Time Machine," etc.



Interior illustration to H. G. Wells' novel *The War of the Worlds*. It was reprinted in *Amazing Stories* in August 1927.

assemble enough mirrors to ignite a wooden ship.

H.G. Wells envisioned even more powerful light beams in his 1898 novel *The War of the Worlds*, in which Martian invaders were armed with heat rays that seem uncannily similar to powerful infrared lasers. The weapons generated intense heat "in a chamber of practically absolute non-conductivity," and used a "polished parabolic mirror of unknown composition" to focus it into a powerful beam that ignited anything flammable, softened iron, and made water flash into steam.

Death rays and nuclear defense

The idea of a "death ray" that kills on contact dates from a 1915 book by Arthur B. Reeve titled *The Exploits of Elaine*. The

hero, a scientific detective named Craig Kenney, detects "some kind of wireless rays—infrared I think," which burn wood when reflected from a mirror, but kill people if they illuminate their heads, leaving only a coin-sized dark spot. The phrase "death ray" appears only in a chapter title. However, after a silent movie serial was made from the book, it lingered in the popular imagination.

Later science-fiction writers armed characters with ray guns, death rays and blasters that could kill or stun their targets. Little or no science fact was behind the fictional weapons, but it wouldn't do to send Buck Rogers roaming the 25th century with a six-shooter. Even future President Ronald Reagan got into the act, to keep a spy from stealing an "inertia projector" that could shoot down planes in the 1940 film *Murder in the Air*.

Real directed-energy weapons grew from experiments in wireless power transmission at the end of the 19th century, particularly by inventor Nikola Tesla. World War I stimulated more inventors to propose super-weapons. British inventor Harry Grindell Matthews made headlines in 1924, when he boasted that his "death ray" could kill people from afar as well as disable machine guns and aircraft engines. He failed to convince the British Army to buy his invention, but he helped

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inspire the invention of radar, and reports of mysterious beam weapons continued for a couple of decades.

The atomic bomb became the ultimate weapon after World War II, and it was so terrifying that it spawned hope for even more potent weapons. George Pal's 1953 movie version of *The War of the Worlds* features Martian invaders that are superior to all terrestrial weapons when they march through atomic mushroom clouds, their heat rays blazing.

Yet in the real world, a panel of top-level scientists in 1945 saw little hope that directed-energy weapons could block a nuclear attack. Instead, the Pentagon turned to missiles to defend against long-range nuclear bombers and the intercontinental ballistic missiles developed in the 1950s. Missile defense was a top priority for ARPA when the laser came along.

The laser was a big step beyond the maser that Charles Townes had developed at Columbia University with military research funding. Nobody thought of masers as powerful beam weapons. When Townes and Arthur Schawlow proposed an optical version, they envisioned that it would be used as an oscillator for optical communications. The possibility of a laser weapon was the brainstorm of Gordon Gould, who, as a 37-year-old graduate student at Columbia, had come up with his own solution to the problem of building an optical-frequency maser, or, as he preferred to say, a laser.

Gould left Columbia to pursue a patent while Townes and Schawlow worked on a research paper. Gould realized that a laser resonator could generate a powerful beam that could be focused to an intense, diffraction-limited spot. Goldmuntz, president of Technical Research Group, a military contractor in New York, helped Gould turn the patent application into a TRG contract proposal. After unsuccessfully pitching the laser to the Air Force Office of Scientific Research and the Army Signal Corps, which had funded earlier TRG research, they tried ARPA.

Their pitch was laden with bold ideas. Gould told ARPA that a laser spot could measure the distance to enemy targets and project bright spots designating targets for U.S. missiles. He concluded by saying that a beam could be focused to 10,000 times brighter than the sun, intense enough to trigger chemical reactions or perhaps ultimately cause nuclear fusion. Gould expected early lasers to deliver watts of power and said that ultimately lasers might become powerful enough to destroy nuclear missiles.

Paul Adams, ARPA's optics expert, loved the plan. A review panel liked the prospects for laser communications, target designation and rangefinding, and approved the \$300,000 that TRG had requested. Goldmuntz would have been happy with

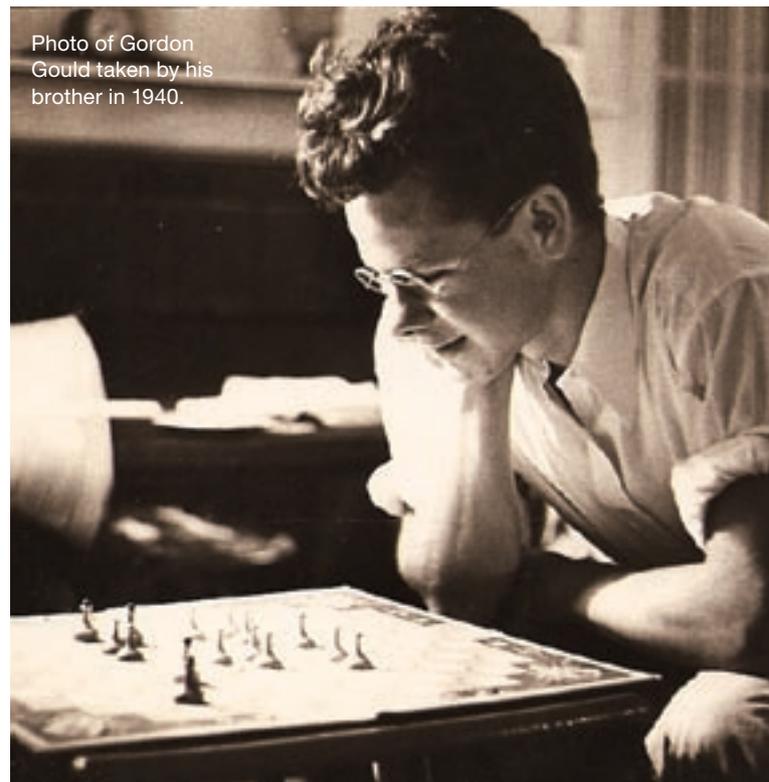


Photo of Gordon Gould taken by his brother in 1940.

Wikipedia Commons

that, but Adams pressed for more money. Within days, TRG had a contract for \$999,000, and a mandate to work in parallel on all three of the laser approaches that Gould had suggested—optical pumping of a metal vapor, optical pumping of a solid, and discharge excitation of a gas.

Then the Pentagon classified the program, a big problem for Gould, whose youthful dalliance with communism had already cost him two jobs. "They wouldn't keep you from working on your own project," Goldmuntz said, and hired lawyers to help Gould get a clearance.

They got nowhere. Gould was stuck in a windowless office, and TRG eventually had to tear down a wall so he could go to the men's room without passing through a secure zone. Cleared scientists could ask Gould for help, but they couldn't tell him about their experiments, so he couldn't work effectively.

"L.A. Man Discovers Death Ray"

In the end, Theodore Maiman at Hughes Research Laboratories in California beat TRG, Bell Labs and Columbia by building an elegant little pulsed ruby laser. He was elated by

his success, but disturbed when a reporter from the *Chicago Tribune* asked at a July 7, 1960, press conference if the laser was a “death ray” weapon. Maiman tried to duck the question, but the reporters were persistent, and Maiman finally admitted that he couldn’t rule out the possibility that the laser could be used as a weapon. The next morning, the *Los Angeles Herald* carried a headline in two-inch red type, “L.A. Man Discovers Science Fiction Death Ray.”

The news stunned better-funded groups that had been trying to make lasers at Bell Labs, TRG and Columbia. All had been trying to build continuous wave lasers; none had thought ruby would work. Maiman’s laser was small enough to hold in his hand, but it packed an impressive power into its millisecond pulses. Within a couple weeks, Ron Martin at TRG had made the world’s second ruby laser. ARPA was encouraged.

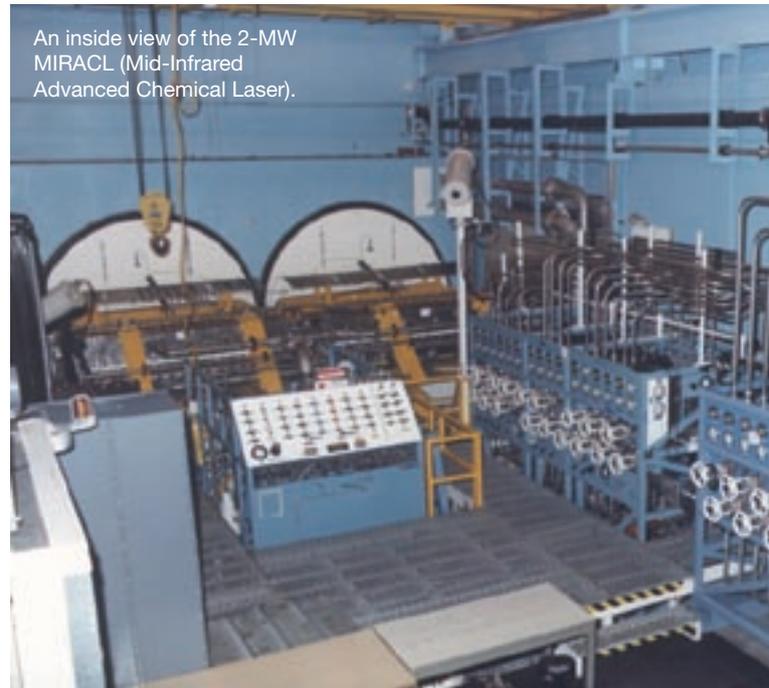
Even before Maiman’s report, ARPA had added \$722,000 to TRG’s contract to speed laser development. Afterwards, the agency expanded its program to study laser mechanisms, materials and beam interactions with targets. The Air Force almost immediately gave Maiman a contract to develop ruby lasers, and other military labs started their own laser projects. The armed services focused on developing lasers for near-term applications in missile guidance and communications; ARPA focused on its long-term goal of high-energy laser weapons.

By late 1961, other lasers had been demonstrated, most notably the neodymium-glass laser by Elias Snitzer at American Optical and a helium-neon one by Ali Javan and William Bennett at Bell Labs. Bill Culver, a young physicist at the Institute for Defense Analyses, organized a four-day brainstorming session between Christmas and New Year’s on the prospects for laser weapons. “Most people came there with the idea that it was crazy. They wanted to stop it,” Culver recalls.

But nuclear-weapon scientists revealed that nuclear reentry vehicles were very sensitive to thermal shock, so laser heating might shatter them. And participants worried that opposing laser weapons could make them vulnerable to the sort of attacks suffered by J. Robert Oppenheimer after he opposed development of the hydrogen bomb. In the end, all agreed to continue laser weapon research, and the Pentagon approved \$5 million for the program.

An initial wave of optimism spread rapidly. Air Force chief of staff General Curtis LeMay jumped on the laser bandwagon, saying on March 28, 1962, that “beam directed energy weapons would be able to transmit energy across space with the speed of light and bring about the technological disarmament of nuclear weapons.” The Air Force Systems Command sought to develop ground-based antisatellite lasers and perhaps a space-based laser weapon in a five-year, \$27 million “Project Blackeye.”

ARPA’s Project SEASIDE boosted pulse energy from neodymium-glass and ruby, but also revealed serious problems. Hughes reached pulse energies of 30 watts with a ruby oscillator-amplifier. Westinghouse pushed Q-switched ruby pulses to 60 to 80 joules, but the rods shattered from the heat. American



An inside view of the 2-MW MIRACL (Mid-Infrared Advanced Chemical Laser).

US Army Space and Missile Defense Command

Optical produced 35-J pulses from neodymium-glass, but its rods also shattered. Discouraged by these heat-dissipation problems, ARPA scaled down its laser program around 1965.

High-energy gas lasers

Meanwhile, gas lasers entered the high-energy laser race. Early on, Gould had recommended scaling them to high powers because flowing the gas could remove heat easily, and their refractive index varied little with temperature. But gases seemed too tenuous to deliver much power, and others shrugged off his ideas. “Nobody paid any attention; he was this outsider without a clearance,” Culver recalls.

The first sign of encouragement that gas lasers might yield high power came from the carbon-dioxide laser. C. Kumar N. Patel at Bell Labs initially generated tens of milliwatts on 10- μ m vibrational transitions by electrically pumping CO₂ molecules in a 1.5-m tube. Adding nitrogen and helium, he reached 200 W continuous wave by mid-1965—more than enough for his research. But that only whet the appetites of military labs, which stretched lengths of laser tubes to almost absurd scales. Hughes reached 1.5 kW, but needed a 10-m oscillator followed by a 54-m amplifier.

The key breakthrough that led to the first true high-energy lasers came from pondering the problem of heat transfer for a laser with the one-megawatt sustained power needed to damage a target. Arthur Kantrowitz and Ed Gerry at the Avco Everett Research Laboratory near Boston realized that, at the 0.1 percent efficiency of early lasers, a gigawatt of waste power would have to be removed from a megawatt laser.

In 1973, the Navy commissioned construction of the 400-kW Navy ARPA Chemical Laser, which in 1978 became the first chemical laser to shoot down a missile in flight.

Rocket engines generated such powers, so they tried a rocket-like approach to laser gas flow—burning fuel to generate hot CO₂ that they mixed with nitrogen and expanded through special nozzles at supersonic velocity. Highly excited CO₂ molecules stayed in the upper laser long enough to create a population inversion. “It was a very simple thing, but not a very efficient laser,” recalls Gerry.

First demonstrated in 1966, the gas dynamic laser was kept classified until 1970. By then Avco had exceeded 100 kW, although Gerry was only allowed to report 50 kW. The power level was impressive for a laser, but only comparable to that of a Volkswagen engine. After drawing the analogy at a press conference, Gerry says, “I was surprised to find a headline in the paper the next morning, ‘Laser Powers Small Car.’”

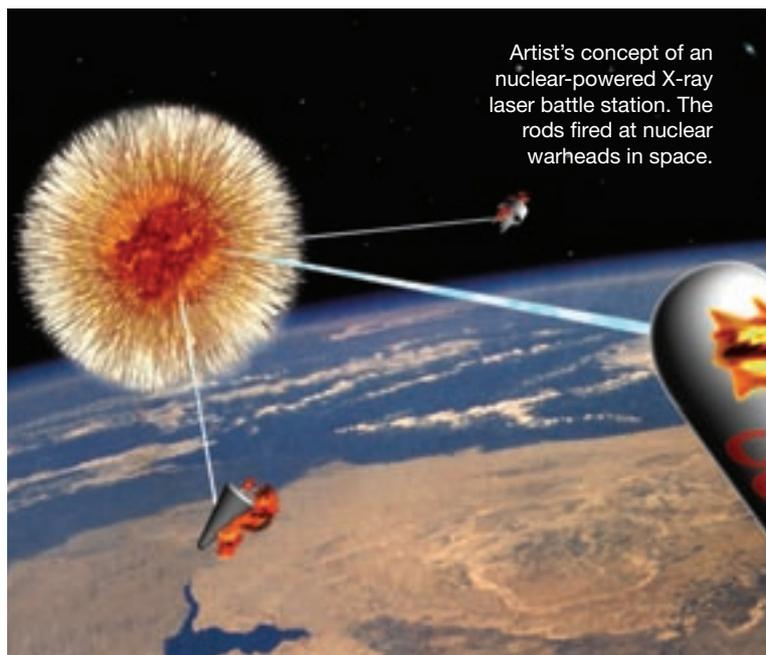
Avco built three 150-kW gas dynamic lasers for tests by the Air Force, the Army and the Navy. Moving targets proved a challenge. When the Air Force tried to hit a drone flying figure-eight patterns, the beam first locked onto and melted a weather tower before managing to shoot down a deliberately weakened drone in 1973.

Hoping a bigger and better laser would improve results, the Air Force squeezed a 400-kW gas-dynamic laser into a military version of a Boeing 707 to make the Airborne Laser Laboratory. After a series of challenges, the Airborne Laser Lab started shooting at target missiles from the air in 1981. However, it took two more years before it finally shot down an air-to-air missile over the Naval Weapons Center in China Lake, Calif.

Chemical lasers

The gas-dynamic laser was limited, both by its 10- μ m wavelength and a combination of size and complexity that prompted one critic to call it a “ten-ton watch.” Strong sea-level absorption of the 10- μ m beam led the Navy to turn to the chemical hydrogen-fluoride laser, in which fuels containing hydrogen and fluoride burned to produce excited HF molecules that generated a laser beam after flowing through nozzles. HF containing normal hydrogen emits at 2.7 to 3.0 μ m, a band strongly absorbed by air; however, HF that contains the heavier deuterium isotope emits at 3.6 to 4.0 μ m, which air transmits much better.

TRW built the first chemical laser to exceed 100 kW, the Big Demonstration Laser. In 1973, the Navy, impressed by Air Force tests of that system, commissioned construction of the 400-kW Navy ARPA Chemical Laser (NACL), which in 1978 became the first chemical laser to shoot down a missile in flight. TRW then built the first megawatt-class laser, the



Artist's concept of a nuclear-powered X-ray laser battle station. The rods fired at nuclear warheads in space.

Lawrence Livermore National Laboratory

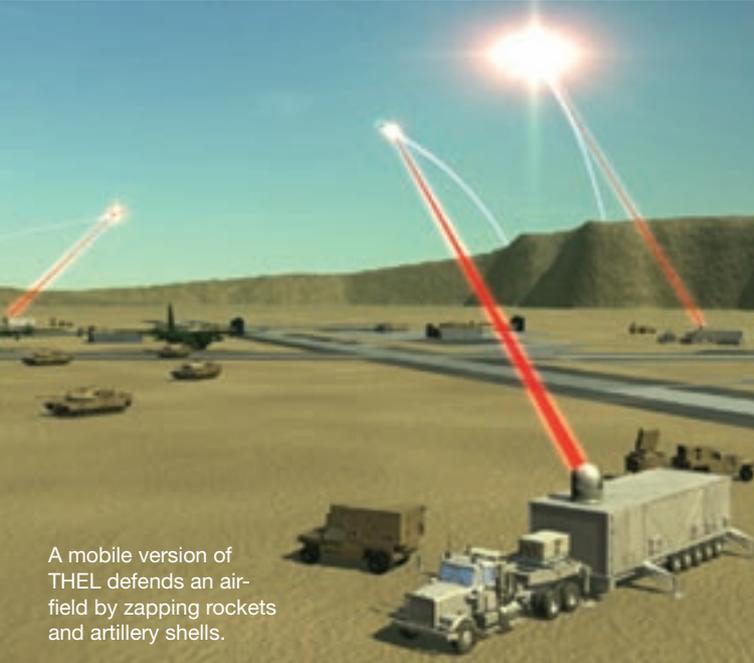
Mid-Infrared Advanced Chemical Laser (MIRACL). Completed in 1980, it could emit 2 MW, although only for seconds at a time.

MIRACL was huge, but size alone didn't discourage Navy officials, who envisioned installing lasers on their biggest ships to defend against missile attacks. However, raw laser power alone did not make an effective weapon system. Delivering the laser beam through the atmosphere to a moving target proved a tremendous challenge. Absorption of laser energy heated the air, particularly in the center of the beam, creating a negative lens effect with lowest refractive index in the center of the beam, and causing “thermal blooming” that spread the beam over a larger area, reducing power on target. Refraction caused by air currents and turbulence also bent and broke up the beam. Unable to focus destructive energy onto targets, the armed services lost their initial enthusiasm for laser weapons by the early 1980s.

The Star Wars era

Meanwhile, laser weapons received renewed attention for their use in new space-based defenses against nuclear missile attack, echoing Roy Johnson's idea from the dawn of the space age.

Renamed the Defense Advanced Research Projects Agency in 1972, DARPA spent most of the 1970s trying to develop



A mobile version of THEL defends an airfield by zapping rockets and artillery shells.



Beam director used by THEL to shoot down rockets and mortars in field tests.

high-power lasers that would emit at short wavelengths. The agency first considered X-ray lasers, then turned to free-electron, excimer and blue-green lasers. Around 1980, DARPA shifted its emphasis again, to demonstrating three key subsystems for space-based defense against nuclear missiles in their boost phase, when they are most vulnerable to laser attack. Space was a challenge, but it avoided atmospheric transmission problems.

The laser centerpiece was ALPHA, a 2.7- μm HF laser intended to generate 5 MW in space. The optical component was LODE, the Large Optics Demonstration Experiment, a 4-m mirror intended for space use with a high-power laser. A testbed called TALON GOLD was intended to demonstrate pointing and tracking with 0.2 μrad accuracy in space.

But Lockheed aerospace engineer Maxwell Hunter put forth the boldest plans on the space laser frontier—a fleet of 18 orbiting chemical laser battle stations, which he claimed could block a surprise attack by thousands of Soviet nuclear missiles. Each station would include a 5-MW HF laser, a 4-m mirror, a pointing and control system, and enough laser fuel to fire 1,000 shots at targets up to 5,000 km away. The space shuttle was to carry the 17,000-kg satellite to orbit in its payload bay.

Malcolm Wallop, then a freshman Republican senator from Wyoming, signed onto the plan in 1979, and proposed building the system for \$10 billion. Critics scoffed, and his proposal got nowhere. Even after Ronald Reagan was elected president in 1980, Wallop had to settle for a \$50 million increase in the Pentagon's laser research budget in fiscal 1982.

Reagan's Strategic Defense Initiative took over the DARPA space laser projects in 1983, as part of its effort to develop a layered defense system, which targeted enemy missiles at various points during their flight. SDI poured money into bomb-driven X-ray lasers (see May 2008 OPN) as well as chemical lasers, and researched other schemes, including building massive ground-based free-electron lasers that would direct their beams to orbiting relay mirrors that would aim the beams at targets in space or on the ground.

Several billion dollars per year were spent on SDI, but only a small fraction of that went into high-energy laser weapons. In fiscal 1986, SDI laser weapon spending peaked at about \$500 million, divided among chemical, excimer, X-ray and free-electron lasers. The total was 100 times more than the Pentagon had allocated a quarter-century earlier, but it dropped the following year as SDI shifted priorities. The X-ray laser ran into serious problems; progress was slow on chemical lasers; and SDI shrank as the Cold War waned. Only in 1991 did ALPHA achieve megawatt-class output.

The Pentagon dropped work on excimers and ground-based free-electron laser weapons in the 1990s, keeping chemical lasers alive as the Space-Based Laser Program. But progress was slow; by 2000, plans for an on-orbit test had slipped to 2013, and soon afterwards the project disappeared from the budget.

New laser weapons

Once the Soviet Union dissolved, the United States changed its missile defense strategy dramatically, to the more manageable task of defending against a few missiles launched by a "rogue state." Development of the Airborne Laser, a megawatt-class laser in a modified Boeing 747, started in the 1990s. The Airborne Laser is intended to fly near the borders of countries suspected to be planning a missile attack, ready to shoot down

Lockheed aerospace engineer Maxwell Hunter put forth the boldest plans—a fleet of 18 orbiting chemical laser battle stations, which he claimed could block a surprise attack by thousands of Soviet nuclear missiles.

at boost-phase missiles up to a few hundred kilometers away. Instead of an HF chemical laser, it uses a chemical oxygen-iodine laser (COIL), which emits at 1.3 μm after a chemical reaction frees excited oxygen—which transfers its energy to iodine atoms. Developers added adaptive optics to its beam-control system in an effort to improve beam transmission.

Although the Airborne Laser may seem modest compared to SDI, it has fallen years behind schedule. In 2002, it was scheduled to start shooting at airborne targets late the following year; those tests are now to be conducted in late 2009. Plans to build additional Airborne Lasers have been put off until the tests are completed.

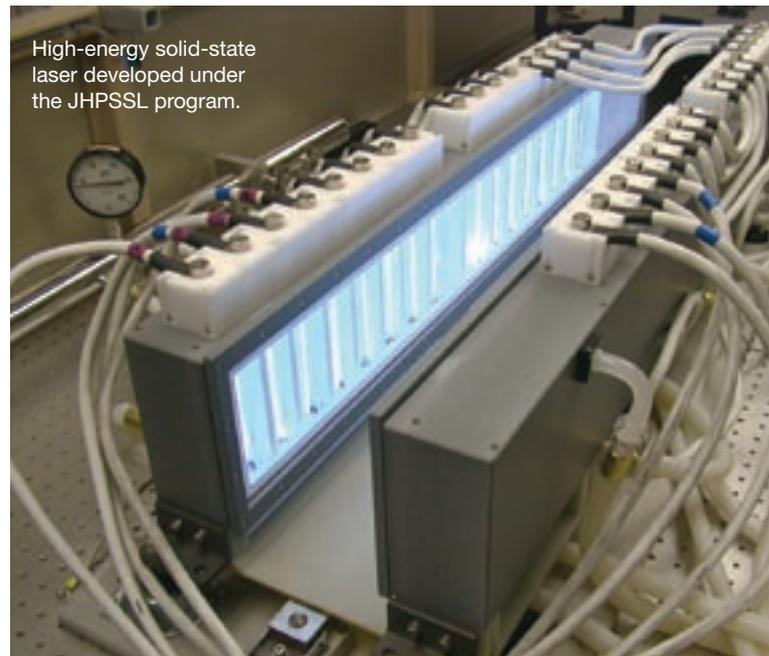
The Air Force also is testing a smaller COIL, weighing about 6 tons and emitting about 100 kW, called the Advanced Tactical Laser. Housed in a highly maneuverable C-130H aircraft, it is intended to test how well a laser weapon can execute precision strikes and other operations from the air.

But the laser weapon technology that looks most promising for the battlefield of tomorrow is one abandoned more than 40 years ago—solid-state lasers. Today's diode-pumped solid-state slab and fiber lasers are a long way from early flashlamp-pumped ruby and neodymium-glass, and their impressive improvements in power and efficiency are making them look better for battlefield use than gas lasers.

A case in point is defense against short-range rockets, artillery and mortars, low-tech weapons often used by insurgents dispersed among civilian populations. Starting in 2000, the United States and Israel used a ground-based chemical laser called THEL (Tactical High-Energy Laser) to shoot down a series of such targets on test ranges. The results looked promising, but the bulky chemical laser posed the logistic nightmares of trying to supply special fuels to complex systems on the battlefield.

Instead, they want a solid-state diode-pumped laser that can run on electric power from a field generator powered by the same diesel fuel that keeps military vehicles running. Developers have already demonstrated modules with average power of 25 kW, and the Joint High Power Solid-State Laser (JHPSSL) program has targeted laboratory demonstration of 100-kW diode-pumped slab lasers in late 2008 or early 2009. Plans call for a field demonstration version around 2012, with a longer-term goal of 400-kW average power, which would make a more effective weapon. Developers hope adaptive optics and the short range will control atmospheric transmission problems.

The remaining challenges are formidable, including thermal management, optics and possibly coherent beam combination. But solid-state laser technology has come a long way. And one



High-energy solid-state laser developed under the JHPSSL program.

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thing that that hasn't changed in a half-century of laser weapons is that developers are optimistic that solutions to their problems are only a few years away. ▲

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