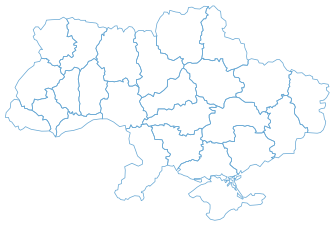
Students in Kharkiv, Ukraine, participating in optics activities during the 2018 International Day of Light.

IRE SPIE and ILTPE (IRE) Optica Student Chapters



Optics in Ukraine

Glorious Past, Uncertain Future

Invasion and war have disrupted Ukrainian science—and rebuilding it deserves the world's attention and resources.

Svetlana V. Boriskina

Perhaps every optics research lab has at least one helium-neon laser—a familiar device, and one of the lasers used in manufacturing the electronic and photonic chips used in smartphones, computers, cars and more. What is less known is that before 2022, about half of the world's semiconductor-grade neon—and about 90% of the neon used in the United States—came from two Ukrainian companies located in Odessa and Mariupol. Further, economic manufacture of neon on such a scale has been possible only because the gas is a byproduct of large-scale steel manufacturing at the latter city's Azovstal metallurgical plant.

Famously, in April 2022, the Azovstal plant became the last stronghold of Mariupol's Ukrainian defenders in the current war with the Russian Federation—and the plant now lies in ruins. World neon prices, which had already risen 600% after Russia's 2014 annexation of the Crimean Peninsula, have seen a new surge and, as of August 2022, were up some 5000% from levels before the war. The shortage of neon from Ukraine is one factor currently affecting chip availability and costs worldwide.

This single example graphically illustrates why Ukraine matters for world science and society. And there are others. The city of Kharkiv, for example, has been home to many

Left: The Azovstal metallurgical plant in Mariupol, Ukraine, after Russian bombardment. Right: The ruins of the Instrument-Making Plant in Izyum, Ukraine. A. Ermochenko / Reuters; Suspilne Ukraine

optics and photonics research and manufacturing facilities. The State Scientific Institution "Institute for Single Crystals," as the name suggests, is a leader in research and manufacture of high-quality single-crystalline materials, such as sapphires, for optoelectronics, space technologies and medicine. Its crystals find use in applications from tomography to security systems, and in leading international high-energy physics facilities ranging from CERN's Large Hardon Collider in Switzerland to Fermilab in the United States to Daya Bay in China.

But Kharkiv, too, has been hit hard by the war. Since February, the institute's buildings there have been shelled by Russian artillery and missiles. Near Kharkiv, the Instrument-Making Plant in Izyum—a small town under Russian occupation from early March to mid-September 2022—had been one of only a handful of facilities worldwide that boasted a full manufacturing cycle in optics, from making the highest quality optical glass to final optical product design and manufacture. Today, it lies abandoned and ransacked.

Before February 2022, many people would have struggled to locate Ukraine on a world map. Now, for tragic reasons, most anyone can. This feature spotlights the war's impact on the Ukrainian academic, industrial and military communities that focus on optics and photonics research, the displacements and uncertainties imposed by the war—and the possible path to future renewal.

Soviet shadows

The success of Ukrainian optics and photonics manufacturing technologies has come from the strong academic and research infrastructure in Kharkiv, Kyiv, Lviv, Chernivtsy and other scientific hubs in the country. Optics research in these cities came of age while Ukraine was part of the Soviet Union (1922 to 1991), and is shadowed by some of that period's troubling politics.

The Kharkiv Institute of Physics and Technology (KIPT), for example—the site of a unique cold-neutron source facility developed in collaboration with Argonne National Laboratory, USA—was the original home of physicist Lev Landau's research group in the 1930s, when the school was known as the Ukrainian Physics and Technology Institute (UPTI). In 1932, at just 24 years of age, Landau—who would go on to win the Nobel Prize in physics 30 years later—was appointed head of the UPTI department of theoretical physics. Together with his students, he would go on to lay the theoretical foundations of many areas of modern photonics and other branches of physics. The ten-volume *Course of Theoretical Physics* that he co-authored with his student Evgeny Lifshitz became a must-have "holy book" for the photonics research community.

Less known in international circles is that Landau was demoted and forced to flee Kharkiv in 1937, during a wave of Stalinist terror. He moved to Moscow and for a while enjoyed political protection from Pyotr Kapitza, the founding director of the Institute for Physical Problems—but even Kapitza could not save Landau from arrest in 1938 on charges of "anti-Soviet activity." Though he was released on bail, Landau was never cleared of these charges during his lifetime, and was only rehabilitated posthumously in the 1990s. Some of his colleagues in Kharkiv, including Lev Shubnikov, were less fortunate, perishing in the Stalinist Great Purge.

Such factors have led, from the 1930s onward, to "brain drain" for Ukrainian science generally and for optics and photonics in particular. Most Ukrainian male scientists and many female ones fought in World War II and many did not return from the battlefield. After the war, some Ukrainian academics advocating for a more independent Ukraine found themselves sent to the gulag, far from Ukraine. Others moved voluntarily

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out of Ukraine, to Moscow, St. Petersburg (then Leningrad) and Novosibirsk, when offered more prestigious or lucrative positions.

The collapse of the Soviet Union in 1991, accompanied by widespread unemployment, also sent waves of scientists and educators to other countries. Many of my classmates from the Radiophysics Department of Kharkiv National University now reside and work not in Ukraine, but in Europe, Asia and the Americas. Ukraine was also heavily affected by a wave of Jewish emigration to Israel, which began in the 1970s in the Soviet Union and accelerated after 1991.

"Universities in exile"

The term "university in exile" was originally introduced to describe scholars who fled Germany for the United States and other countries before World War II, to reestablish themselves in academic world. The Russian invasion of Ukraine—which started in 2014 and has intensified with the 2022 war—has given the term a whole new meaning, having led to the displacement not only of individual scientists but of entire academic and research institutions.

Some universities have had to relocate twice in the past eight years—once in 2014, and again in 2022. Others, like the brand-new Metinvest Polytechnic University founded in Mariupol in 2020, never really had a chance to get off the ground. And research links with still other Ukrainian facilities, such as the Crimean Astrophysical Observatory in Nauchny, have been temporarily lost since Crimea's annexation by Russia.

Fortunately, new communications technologies—largely enabled by optics and photonics—have allowed many of the displaced universities to operate remotely, by offering online programs. Luhansk Taras Shevchenko National University, for example, continued offering the majority of its master's and Ph.D. programs online, and is now the leader in online learning in Ukraine.

Even more remarkable have been the adaptations of online teaching, learning and working to fit the needs of a country at war. Employees of companies like Skylum, the Kyiv-based developer of a popular, AI-enhanced photo-editing app, continued working on their laptops in bomb shelters during Russian air raids. And the world has also seen stunning images of Ukrainian academics

Physics researchers at the Ukrainian Institute of Physics and Technology (UPTI), Kharkiv, in the 1930s. Left to right: first row, L.V. Shubnikov, O.I. Leipunskii, L.D. Landau, P.L. Kapitza; second row, B.M. Finkelshtein, A.M. Trapeznikova, K.D. Sinelnikov, Yu.M. Ryabinin.

AIP Emilio Segrè Visual Archives

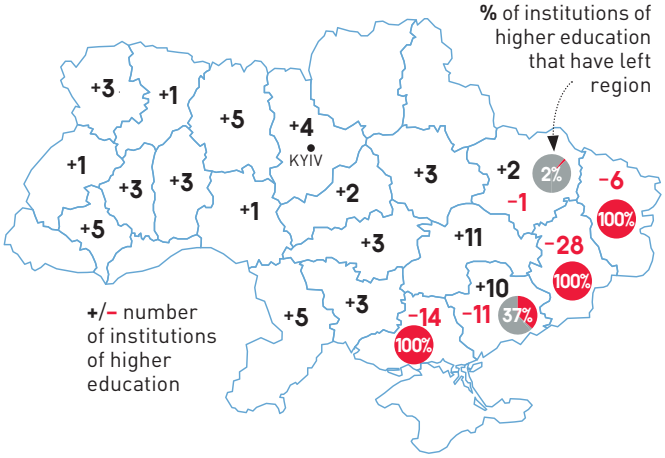
teaching from their basements and even from trenches, and of soldiers defending their thesis projects online from the battlefield, leveraging optically driven technologies from mobile communications to solar energy to smartphone screens.

Optics on the battlefield

Optical technologies also play a much more important, direct role in the modern war effort. They provide vision and communication on the battlefield that have allowed the Ukrainian Army to gain tactical and strategic advantages over its formidable adversary.

Iconic images from the Ukraine–Russia war include portable, infrared-guided Javelin anti-tank missiles instrumental in stopping the initial wave of the Russian Army in February 2022; SpaceX Starlink modules for internet communication; and solar-panel-enabled Powerwalls that provide energy to clinics in hard-hit Ukrainian cities such as Irpin and Borodyanka. Other essential optical devices on the battlefield include laser sights, cameras, binoculars and night-vision goggles.

In an effort to gain an ultimate optical advantage, the Ukrainian public and volunteers recently crowdsourced and purchased a surveillance satellite. The small, agile synthetic-aperture radar satellite, developed



Since the Russian invasion began in 2014, multiple universities in the Ukraine's eastern region have moved operations to safer western regions.

Adapted from t.me/uawarinfographics

by the Finland-based microsatellite company ICEYE, can collect images day and night and in any weather.

The science–military nexus

Another battle being fought by Ukraine and its allies lies in the political sphere—the need to limit Russia's access to sensitive technologies, including optical ones, that could be used to further the Russian war effort. The weapons used in that political battle include export controls and restrictions on scientific collaboration with Russian institutions.

The underlying concern is an important one, as science in this region has, since before the Cold War, been deeply intermeshed with military might. One reason Lev Landau fell out of favor with the Communist rulers was his disdain for applied and, especially, defense-focused research. In contrast, Pyotr Kapitza and other academicians who enjoyed the Soviet government's favors and research funding for their facilities contributed heavily to various Soviet military programs.

Most research institutions and optical-industry players contribute to defense efforts in some way and can benefit from access to sensitive Western technologies. Ukraine's Izyum Instrument-Making plant started production in 1923, by acquiring access to the glass-making patents and blueprints from the British optical-glass pioneer Chance Brothers and Company. Earlier attempts by Imperial Russia to establish a glass-making facility in St. Petersburg had failed, in part because wood-burning temperatures are not high enough for glassmaking (something any Minecraft player knows today).

The Izyum plant's designers took advantage of easy access to coal from Ukraine's Donbas region, and also adopted the strategy of building a closed glass-and-optical-instrument production cycle established by the Schott and Zeiss plants in Jena, Germany. Today, defense-related products still constitute the bulk of the Izyum plant's output. The laser guidance block of Ukrainian-made anti-tank systems Stugna-P, which rival Javelins in efficiency, is made there, along with many other components for optical surveillance, guidance and communication equipment.

During the postwar Soviet period and the days of the Cold War, research institutions in Russia and Ukraine became more and more focused on defense-related topics, including high-energy physics related to the Soviet nuclear program. Even Ukraine's dominance in worldwide neon production traces back to the Cold War. The Soviet Union invested considerable funds in facilities to make large amounts of neon to support its futuristic space-based laser weapons program. Only after the Cold War ended were these facilities re-oriented to serve a broad worldwide market outside of the war effort.

In Russia today, long after the Cold War, ties persist between high-profile research institutions and the military establishment. After the February 2022 invasion, the US Treasury Department imposed sanctions on many Russian high-technology entities. These include well-known academic and innovation hubs such the Skolkovo Institute of Science and Technology (Skoltech) and the Moscow Institute of Physics and Technology (PhysTech). While centered on research and innovation, Skoltech enjoys partnerships with many Russian enterprises—including Uralvagonzavod, the United Engine Corporation and the United Aircraft Corporation—that develop materials and components for tanks, ships and aircraft now being used in the war against Ukraine.

To collaborate or not to collaborate?

These military-academic ties have sometimes bitterly divided researchers, in Ukraine and in other countries, according to their willingness or refusal to maintain research collaborations with colleagues in Russia.

Collaboration is, of course, essential in academic research. Even a genius like Landau, during his education in Germany, Denmark, England and Switzerland in 1930s, met with and learned from Albert Einstein, Max Born and Niels Bohr. Working in Copenhagen with the latter, Landau also communicated with other brilliant young physicists of the time, including Werner Heisenberg, Wolfgang Pauli, Rudolf Peierls, Felix

Russia's invasion of Ukraine has triggered a redrawing of the map of international scientific cooperation.

Bloch, Eugene Wigner and Paul Dirac—many of whom later visited Landau's group in Kharkiv.

Russia's invasion of Ukraine, however, has triggered a redrawing of the map of international scientific cooperation. Numerous countries in Europe, the United States and their allies have cut ties with Russian academic and research institutions. For example, my own home institution, the Massachusetts Institute of Technology (MIT), has severed its research connections with Skoltech—an institute that MIT helped to found in 2011—after the February 2022 invasion. Meanwhile, other governments, including China, India and South Africa, are strengthening technological exchange and research collaborations with Russia.

In June 2022, I ran an unscientific, anonymous online poll seeking colleagues' opinions on collaboration with individuals and institutions in Russia. Perhaps not surprisingly, every respondent identifying as Ukrainian by origin (whether working in Ukraine or abroad) was not planning to continue or start new collaborations with colleagues employed by Russian institutions. Some planned to cut all ties with Russian researchers, but the majority had no problem continuing collaborations with Russian scientists working outside of Russia.

Interestingly, the opinions of responders who identified as Russian by origin but who work outside of Russia were not much different statistically, although very few planned to sever all ties with scientists in Russia. In contrast, people who identified as neither Russian nor Ukrainian were significantly less categorical in their opinions, with most planning to continue business as usual.

Another interesting finding from the survey was that most respondents identifying as Ukrainian reported that they speak Russian at home—not a surprising result to me personally, as I and many of my Ukrainian colleagues belong to the same category. But it does underscore that the origins of the war, and opinions about it, do not necessarily lie in divisions tied to spoken language, as Russian propaganda suggests, but in other areas—in part divisions sown by the propaganda itself.

Whatever the war's outcome, the rift between the Ukrainian and Russian scientific communities, and the countries' peoples in general, may take generations to heal. And the war has also ripped apart the Russia's own academic community. In March 2022, an open letter signed by thousands of Russian scientists criticized the country's invasion of Ukraine. At around the same time, the Russian Union of Rectors issued its own statement in defense and support of the war and its stated aims. Some anti-war academics in Russia have reportedly tried to prevent colleagues who have supported the invasion from being elected to the Russian Academy of Sciences—and persecution of academics with anti-war views by university administrators and industrial employers is undoubtedly ongoing as well.

Fedir Shandor, a 46-year-old Ukrainian professor of sociology, has administered exams to students remotely from trenches on the battlefield using mobile technology.
V. Shchadey

Rebuilding Ukrainian science

Of course, the war's impact has been far more devastating for Ukraine's academic and research community. While many female researchers have been able to flee the country, few can find employment to continue their careers abroad, despite the strong efforts of a network of volunteer supporters around the world to provide them with temporary positions. Male researchers have even more limited prospects; at present, Ukrainian men aged 18 to 60 are barred from leaving the country, although there is a continued parliamentary effort to allow students and other professionals to travel.

How can the international scientific community best support Ukrainian researchers? The country's NATO allies are currently running government-sponsored, well-structured training programs for Ukrainian soldiers. But there is no matching systematic effort to support and develop human resources in academia and research.

Fortunately, the same optical and communications technologies that have enabled remote work during pandemic and war can also support Ukrainian science. If crowdsourcing can enable the Ukrainian people to buy a surveillance satellite, it can also help keep them integrated with the worldwide scientific community. Inviting Ukrainian colleagues to participate remotely in research meetings and webinars and collaborating with them on joint publications can be small yet vital steps all can take to at least mitigate the talent loss.

Luckily, some optics and photonics research hubs still thrive in Ukrainian regions not yet heavily affected by the war. A notable example is Chernivtsi University, located in the western part of the country and a home to long-running, unique Ukrainian programs in correlation optics and singular optics. Even northern- and eastern-located academic hubs in Kharkiv, Kyiv and Donbas can be rejuvenated after the war, given adequate political will and research funding. Student chapters of international societies such as Optica, SPIE and IEEE have fueled the pursuit of academic excellence in Kharkiv for the last couple of decades, and can become nucleation sites for Ukrainian science after the war ends.

History shows that such comebacks are possible. Many soldiers, including my own grandfather, returned from fighting in World War II and became successful university professors and researchers. Even a small-scale but targeted effort can make a huge difference. Not just Landau but most of his colleagues at UPTI in the 1930s were only in their mid-20s, with the oldest, Ivan Obreimov, becoming the institute's director at the age of 35. Most had worked and studied abroad before joining the institute, and continued collaborating with their international colleagues. Visits to UPTI by those colleagues helped to maintain research excellence and to train the new generation of scientists. This successful experiment can and should be replicated after the current war.

New opportunities in a time of crisis

The crisis also offers opportunities to reform Ukraine's academic structure, which until recently remained constrained by inefficiencies rooted in its Soviet past and by continued brain drain. As a stunning example of inefficiency, the original UPTI site, where Landau's office can still be found, has long been abandoned and is literally falling apart, despite a prime location. The system of awarding advanced degrees by the National Academy rather than by universities can be improved and brought into line with international best practices. And there is a tremendous opportunity to offer sanctuary in Ukraine for leading anti-war Russian scientists.

Emerging advanced photonic technologies, especially in the field of renewable energy, were already helping Ukraine make a comeback in the energy security before February 2022. A long-devastated site at the Chernobyl nuclear-power plant has recently become home to a

OPTICS IN UKRAINE DURING PEACE & WAR

Ukrainian students participate in optics activities in honor of the 2018 International Day of Light, sponsored by IRE SPIE Student Chapter and ILTPE (IRE) OSA (now Optica) Student Chapters in Kharkiv, Ukraine.

IRE SPIE and ILTPE (IRE) Optica Student Chapters

13th International Conference on Correlation Optics took place in Chernivtsi National University, in 2021. Numerous optics- and photonics-themed conferences have also been held annually in other Ukrainian cities, including Kharkiv, Kyiv and Lviv.

I. Nakonechnyy / Getty Images

Solar farm at the infamous Chernobyl nuclear energy plant. The Solar Chernobyl project consists of 3,762 solar panels spread over 1.6 hectares and was generating 1,024 megawatt hours of electricity a year.

G. Garanich / Reuters

With the help of the international community, Ukrainian science can once again succeed.

solar-energy facility. New research and educational hubs, such as the Ukrainian Open Science Initiative (vilnanauka.com), may not even require physical real estate, instead using online learning and collaboration platforms. A university-level international partnership initiative promoted by the Ukrainian government, the Ukrainian Global University (uglobal.university), may help to bring much-needed reform and resources to the Ukrainian academic sector.

Taking advantage of these emerging opportunities will require a significant effort to make information available in English, currently the international language of science, and to train the future scientific workforce toward English-language fluency. Thousands of Ukrainian children attending grade schools in Europe and the United States during the war can form the core of such a workforce—but Ukraine must work hard to make sure they return. Organizations such as the Small Academy of Sciences of Ukraine (platform.man.gov.ua), a UNESCO center for science education there, led the early STEM educational effort before the war and are ramping up their online learning resources today.

Reportedly, a plaque can still be found hanging on a wall of the main hall of the old UPTI building, with a quote by the German Nobel laureate Fritz Haber. The plaque reads "If you succeed in what you have started, you will have the best physics institute in Europe." With the help of the international community, Ukrainian science can once again succeed. OPN

The original site of UPTI, the home of Lev Landau's research in the 1930s, has long since fallen into disrepair—a symbol, perhaps, of the latent opportunities to rejuvenate Ukrainian science after the current war.
K. Bunovsky / Ukrainian Truth

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The Javelin system, developed in the US, is a "fire-and-forget" missile with a thermal homing head that uses forward-looking infrared technology capable of fast-frame imaging. The weapon's effectiveness has prompted some Ukrainian parents to name their newborns Javelin or Javelina.
M. Ciaglo / Stringer

Starlink, from SpaceX, provides internet connectivity via a constellation of low-Earth-orbit satellites that's resilient to attack. A Starlink system allowed the Azovstal defenders to maintain contact with the command and offer live video interviews under siege.
K. Berdynskykh

The Ukrainian public recently crowdsourced a surveillance satellite from Finland-based ICEYE. The satellite uses synthetic-aperture radar (SAR) technology, with an active phased-array antenna for electronic beam steering. The Crimean Bridge can be clearly seen in this high-resolution SAR image.
Serhiy Prytula Charity Foundation