Israel has become a powerhouse in quantum technologies

A supportive government, available capital, and world-class academic institutions are some of the factors behind the nation's quantum ascendance.

A SUPERCONDUCTING QUBIT is, in this rendering, controlled by quantum orchestration hardware and software made by the Israeli company Quantum Machines.

Ron Folman, a quantum physicist, was taken aback when a delegation of top officials from the US Defense Advanced Research Projects Agency paid an unexpected visit to his lab at Ben-Gurion University of the Negev (BGU) about 15 years ago. "I asked them, 'Why are you here? You have a thousand times more money, scientists, and space,'" Folman recalls. "The head of the delegation answered, 'I heard what you guys are doing, and I wanted to see with my own eyes this Israeli chutzpah.'"

To Folman, the quote neatly characterizes Israel's outsize global footprint in quantum science and technology.

It's no accident that Israel is punching above its weight in quantum fields. Despite the turmoil that has roiled Israeli politics in recent years, the Knesset committed 1.25 billion shekels ($400 million) to a five-year National Quantum Initiative, which kicked off in late 2019. Tal David, an experimental physicist who heads the initiative, says it gained a boost from Israel's economic stimulus program during the COVID-19 pandemic. The program includes $60 million to build the country's first quantum computer, which is expected to consist of 30–40 qubits. Assembly is due to get underway early next year.

"We don't aspire at least in the next few years to beat IBM or Google," says David. "We need to first form a basis for an ecosystem in Israel and that will be the purpose of the project. Maybe in a few years, we'll be able to jump into the deep end of the pond and compete with the big ones."

Today 60% or more of the initiative's funds is spent in academia, says David. Israel consistently ranks high alongside leading European nations by such measures as citations and the number of grants in quantum fields awarded by the European Research Council, of which it is an associate member.

But the initiative's center of mass is beginning to shift to industry, David says, which should further stimulate the explosive growth of the last two years, during which the number of Israeli firms working in quantum tech surged from 5 to 30. The new entries span the gamut of hardware and software for defense and civilian applications. "It's a small ecosystem, but it's developing quite rapidly, and it's quite diverse," he says, adding that "people are trying not to step on each other's toes."

Attracting $75 million in private investment to date, three-year-old Quantum Machines ranks among the top quantum startups in the world by that measure. Mellanox Technologies, which entered the quantum communications business two years ago, was acquired by Nvidia in 2020. Most of the tech giants, including Microsoft, Google, Amazon, Intel, and others, have R&D centers in Israel that serve as spawning grounds for new quantum companies.

Adopting the nickname "Start-Up Nation" from the eponymous best-selling 2009 book, Israel has an existing high-tech innovation ecosystem that includes a government eager to back inventors. That support in turn attracts investment from the nation's substantial venture capital community. "When they see the government is pushing hard, it's easier for them to take the risk," says David. "At some point we are sharing risk with the private sector."

When it comes to high tech, "basically anyone who comes with an idea and is able to prove the concept probably will get some kind of government grant to kick it off," says Shlomi Cohen, CEO of QuantLR, a quantum encryption startup. "At any moment in Israel, there are more than 6500 startups. I think we are second only to the US." (See PHYSICS TODAY, October 2021, page 42.)

The Israeli army, air force, and intelligence community are the "backbone of the [quantum] industry," Cohen says. The military is both a consumer of quantum technology and a source of technical talent for startups. The government-owned defense contractor Rafael Advanced Defense Systems has technology-sharing agreements with academic institutions, including BGU and the Weizmann Institute of Science. Israel's defense industry began taking an interest in quantum sensing about a decade ago, says Nir Davidson, a Weizmann physicist. The national initiative has allocated $40 million to a quantum-sensing consortium composed of five companies and eight academic groups, including Folman's and Davidson's labs.

A similar consortium is organized around quantum cryptography, where David says activity is "moving much faster than we anticipated" from universities to industry, and into applications in large organizations and the government. A third consortium aims to enlarge Israel's presence in quantum computing, where, he says, "we have a very good start, but it's small."

Well positioned

Davidson is developing a cold-atom gravimeter that will be useful both as an accelerometer in inertial navigation systems and in basic science. LightSolver, a quantum-inspired technology, emerged from Davidson's lab. While not technically a quantum computer, the desktop device that is under development will use a coupled laser array to perform computations.

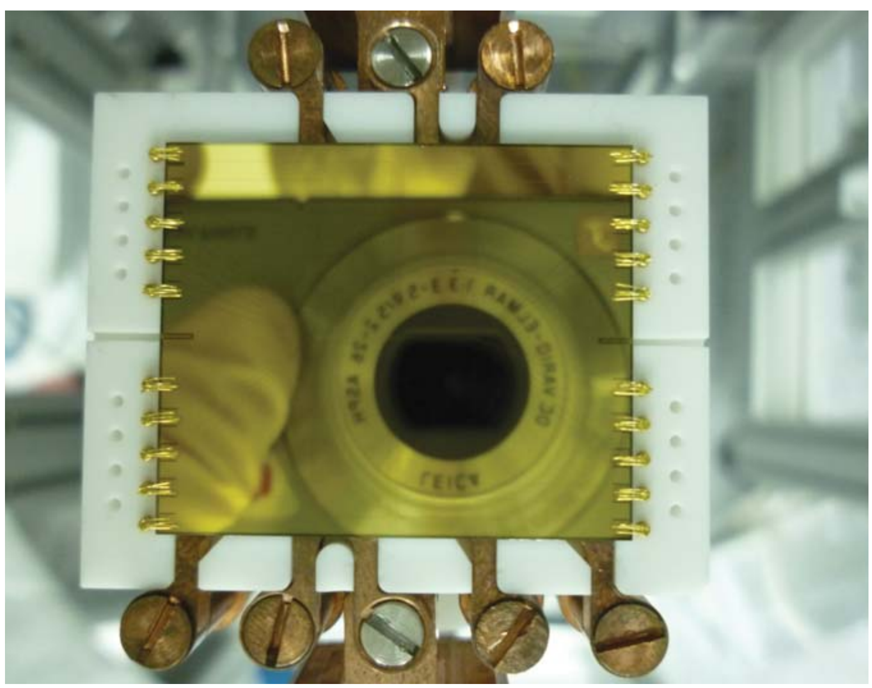
Davidson says the jury is still out on whether quantum computation will come into widespread use in the next decade, but "if it does it will be a game changer, and people will invest huge sums." Well positioned to benefit in that event is Quantum Machines, founded by three physicists who earned their PhDs in the lab of Weizmann physicist Moty Heiblum. The company's quantum orchestration platforms communicate complex software to quantum processors and perform quantum error correction. Notably, the devices will work with whatever type of quantum computing platform becomes dominant. (See "What's under the hood of a quantum computer?," PHYSICS TODAY online, 5 March 2021.)

Itamar Sivan, CEO and cofounder of Quantum Machines, says he has no doubt that quantum computing will take off. "The question is when." He attributes much of his 70-employee company's success to the ready availability of funding. "And there are great engineers and amazing talent in Israel. We can find people here who are both experts in quantum but also have some engineering background." Many of them have come from the defense sector.

Folman's lab has already delivered two quantum prototypes to industry: a compact, robust cold-atom atomic clock and a sensitive magnetic atomic sensor. Amir Waxman left Folman's lab seven years ago to work for AccuBeat, an Israeli manufacturer of rubidium clocks. He continues working with BGU researchers to commercialize the new clock technology he helped to develop there.

Whereas today's commercial atomic clocks are accurate to within one second in 2000 years, the new type will lose just one second in 1 million years, Waxman says. That level of accuracy is important for myriad applications including radar, financial transactions, phase synchronization in electricity transmission, and inertial navigation. For example, a nanosecond can produce errors of several meters in distance as measured with radar, and it is critical to determine the exact sequence of trades in financial instruments, which often occur microseconds apart, he explains. The lab is now developing a miniaturized ytterbium optical-frequency atomic clock that will be five orders of magnitude more accurate than today's clocks.

Folman's lab is working on atom chips—cold-atom devices that include miniature particle sources, vacuum pumps, lasers, and sources of electromagnetic fields to prepare, manipulate, and measure individual atoms. The chips also contain electronics and fiber optics for readout. Just as the miniaturization of the transistor led to the electronic revolution with devices such as laptops and cell phones, atom chips could enable miniaturization of quantum technology, allowing greater accuracy and complexity and lower power consumption, Folman says.

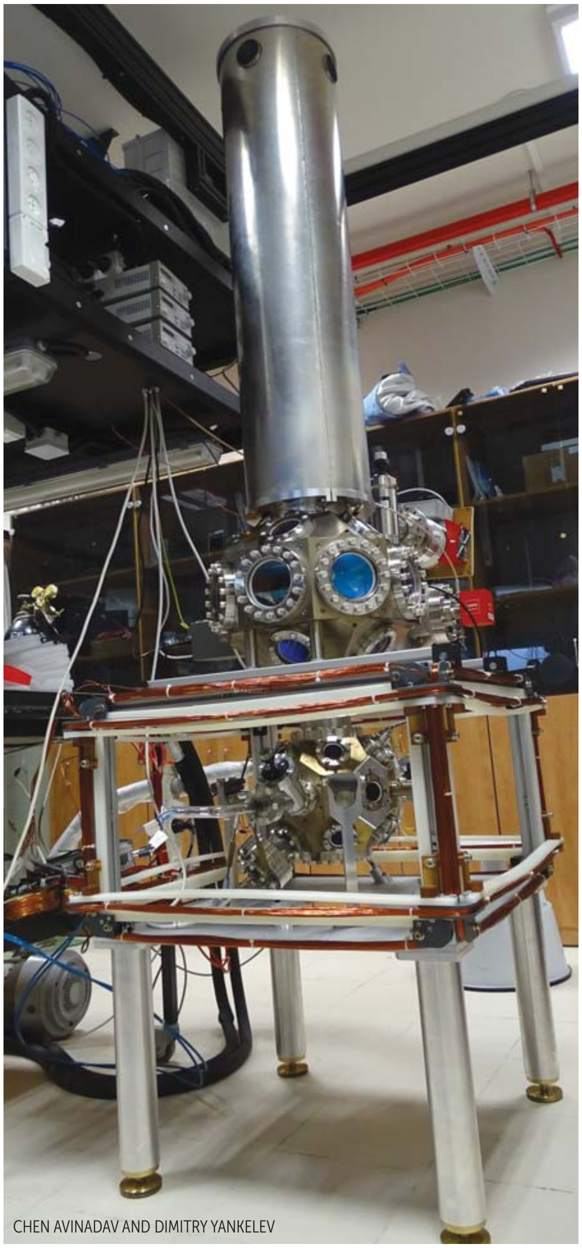

YAIR MARGALIT

AN ATOM CHIP built at the Ben-Gurion University of the Negev nanofabrication facility. The chip is part of a sensor known as a Stern–Gerlach atom interferometer.

Quantum sensors may map the human brain, enable quantum simulators for drug development, and allow long-range quantum communication. Quantum gravitational sensors could produce subsurface images that predict earthquakes and volcanic eruptions. For the military, where stealth technology is in danger of being overcome, “no one knows how to counteract gravitational signals,” Folman notes.

To accommodate the novel designs, geometries, and materials required for atom chips, BGU has built what Folman says was likely the world’s first fabrication facility dedicated to atom-chip R&D. It has orders from R&D centers in Germany, the UK, the Netherlands, Italy, and the US. Companies such as ColdQuanta in Colorado and IonQ in Maryland are already producing such chips for commercial use. (See PHYSICS TODAY, November 2020, page 22.)

By teaching Israelis how to team up to accomplish tasks, mandatory service in the Israel Defense Forces also contributes to the nation’s tech success, says Folman. “They learn to complement and trust each other.” But that’s not enough, he adds. “At the end of the day, you need innovation and ingenuity. People in Israel are very passionate about innovation.”



CHEN AVINADAV AND DIMITRY YANKELEV

A QUANTUM GRAVIMETER setup at the Weizmann Institute of Science. The device was built in collaboration between the Weizmann Institute and Rafael Advanced Defense Systems, the Israeli defense contractor.

An ecosystem

Serendipity played a role in both Raicol Crystals’ and Tabor Electronics’ entry into quantum fields. The two Israeli companies had long-established business lines when quantum technologies began to take off about five years ago. Founded in 1995, Raicol, which manufactures crystals for the laser and optics industries, discovered that physicists were using its nonlinear periodically poled potassium titanyl phosphate crystals in their research to produce entangled photons, through a process called spontaneous parametric down-conversion. Raicol responded to that nascent market by tailoring its crystals for quantum computing, communications, and sensing applications, says Ori Levin, vice president of product management and strategy.

A decade ago, 50-year-old Tabor Electronics learned that some of its physicist customers were using its standard signal generator products in their quantum research. Earlier this year, the company introduced a dedicated arbitrary waveform transceiver designed specifically for quantum computing, communication, and sensing, says Mark Elo, the company’s vice president and general manager of the Americas. The Israel Innovation Authority provided funding to support development of the new instrument.

The two-year-old startup QuantLR expects to start delivering systems for quantum photon data encryption in about a year, says Cohen. “We are using superposition of photons to send the key encryption,” he says. “No one can penetrate a photon. That’s the basic idea of our approach.”

QuantLR’s hardware and software will secure data transmitted through fiber-optic cable over distances up to 100 km, beyond which cooling systems would be required. Most fiber-optic communications between data centers, financial institutions, utilities, infrastructure, and 5G base stations occur within that range, he says. Intrusions will create noise that can be detected, he says, and data flows won’t be slowed because the quantum key will travel over two dedicated channels in the fiber cable, rather than being attached to the data itself.

The company is “in intensive discussions” with data center operators including Amazon, Microsoft, and Telefónica and with 5G companies including Cisco, Nokia, Ericsson, and Huawei.

Looking ahead

David believes there is more to be done. Israel’s number of principal investigators “at the core of quantum,” about 125, is low even for a small country, he says. By comparison, about 300 principal investigators worked at the basic science level in Israel’s 10-year national nanotechnology initiative, which ended in 2016. “One of the biggest challenges we have is to enhance the community—academia as well as industry—while maintaining the high degree of scientific and technological excellence,” he says.

Davidson says that despite its success with European Research Council grants, “where the only criterion is scientific excellence,” Israel hasn’t done as well with international collaborations that are funded by the European Union's 10-year Quantum Flagship program, which began in 2018.

Other disciplines must get involved to fully exploit quantum's potential. "Even if you build the heart of a quantum device, there are many layers and technologies needed to be able to work," says Folman. But materials science, engineering, chemistry, and even biomedicine have yet to team up with physics and computer science, either in Israel or worldwide. "These disciplines today do very little connected to quantum technology. It should be an interdisciplinary effort, and eventually it will be."

Shai Lev, head of business development and partnerships at the quantum algorithm design company Classiq, took on a pro bono role as cofounder of Qubit, a grassroots quantum community effort meant to attract disciplines outside of physics and computer science into the quantum world. While most of the periodic seminars the group organizes are highly technical, some are also devoted to the financial aspects of starting a business. Shir Peri Lichtig, a product operations manager at Soluto and another Qubit co-organizer, says the sessions soared in popularity and became international after the pandemic forced them into virtual mode. Since then, such quantum oracles as Terry Rudolph from Imperial College London; John Martinis from University of California, Santa Barbara; and Chad Rigetti, CEO of Rigetti Computing, have contributed talks.

Paradoxically, another reason for Israel's big presence in tech may be its tiny size. "The maximum distance between universities here is like 200 kilometers," says Lev. "People know each other, and people are always looking for the next thing, and around them you have a vibrant community."

David Kramer

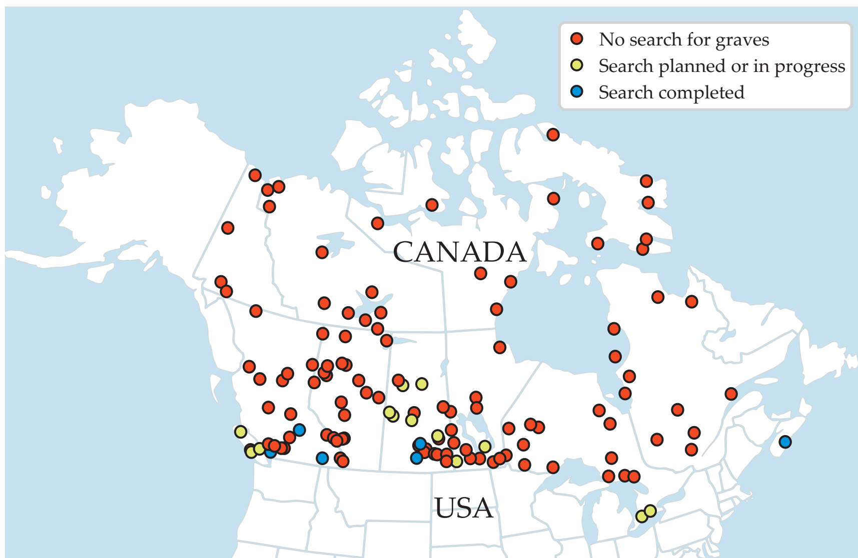
Subsurface imaging shows scale of the tragedy of Indigenous children

Archaeologists and geophysicists in Canada are trying to pinpoint the signatures of unmarked burials by using geophysical methods in varied terrains.

Few applications of radar pulses to locate objects underground have been as emotionally laden as identifying the graves of Indigenous children in Canada. The more than 200 burials located at the former Kamloops Indian Residential School in southwest British Columbia drew worldwide attention this past summer.

As part of the national government's attempt to assimilate Indigenous children into the dominant colonial culture, children as young as six years of age were forcibly taken from their families and sent to that school and many others across the country (see map) that were operated primarily by the Roman Catholic Church between 1890 and 1969. The US government enacted similar acculturation policies at American Indian Residential Schools in the same decades. Many children never returned home.

Ground-penetrating radar (GPR) has been used for several decades in engineering, geoforensics, and archaeology. (See Physics Today, March 2014, page 24.) The Kamloops finding has forged a new interdisciplinary partnership to search throughout North America for other child burial locations without disturbing them. Kisha Supernant, a Métis Indigenous woman and an archaeologist at the University of Alberta, uses maps and spatial data to explore how people in the past interacted with landscapes—for example, comparing the winter mobility patterns of different groups. Liam Wadsworth joined her research group in 2018 as a graduate student. He brought a geophysics background, training in GPR techniques, and a strong motivation to help Indigenous communities find unmarked graves. "Our goal is to make it possible for descendants to appropriately mourn the loss of their ancestral children," says Supernant.



ARCHAEOLOGICAL SURVEYS that rely on ground-penetrating radar have identified unmarked children's graves at several former residential schools for Indigenous children in Canada. (Adapted from data from the National Centre for Truth and Reconciliation, University of Manitoba, Winnipeg, Canada.)

Hyperbolic hints

In GPR technology, an antenna transmits high-frequency radio pulses into the ground and records the return signal and the round-trip travel time. Travel times are sensitive to subsurface discontinuities that reflect, refract, or otherwise scatter the signal. Continuous profiles of subsurface reflections, called radargrams, provide an image of those discontinuities