QUANTUM BREAKTHROUGHS & RELATED PROGRAMS

THE UNIVERSITY OF NEW MEXICO

INTRODUCTION

Quantum technologies stem from exploiting the counterintuitive behavior of systems at the atomic and sub-atomic scales—phenomena like superposition, entanglement, quantum measurement, and coherence. These fundamentals offer new ways of computing, communicating, and measuring which can dramatically outperform classical approaches in certain domains. Key areas include **quantum computation** (designing new ways to process information via qubits and quantum gates), **quantum communication** (secure transmission of information using quantum states), **quantum sensing and metrology** (using quantum systems to make ultra-precise measurements), and **quantum control / measurement** (developing techniques to manipulate and observe quantum systems with high fidelity).

At the University of New Mexico (UNM), there is a strong interdisciplinary program dedicated to advancing such quantum technologies. The **Center for Quantum Information and Control (CQuIC)** brings together physics, engineering, chemistry, and other fields to do research in quantum computation, quantum optics and communication, quantum control/measurement, and quantum metrology. Additionally, UNM is active in cutting-edge projects such as designing a photonic quantum computer under NSF's Quantum Virtual Laboratory program, which aims for scalable, room-temperature photonic quantum technologies.

MARKET OPPORTUNITY

The market for quantum technology is expected to expand rapidly due to notable developments in quantum computing systems and quantum dot fabrication. It is projected to grow at a 33.5% CAGR, reaching a valuation of $86.9 billion by 2031, according to Verified Market Research. Nanostructures and affordable semiconductor integration methods are made possible by quantum dots, which are creating new opportunities in integrated photonics and telecommunications within quantum space. Innovations like the ones below in quantum computing, such as circuit-based leakage detection and randomized dynamical decoupling protocols, are key indicators of growth acceleration in the industry, enhancing the scalability and performance of quantum processors. Sectors such as defense, telecommunications, healthcare, and semiconductor manufacturing are driving rapid investment and adoption in the space. The scalability and performance of quantum processors are being enhanced by innovations in quantum computing, such as randomized dynamical decoupling protocols and circuit-based leakage detection, which create opportunities in the market for technological breakthroughs, as listed below.

TECHNOLOGY BREAKTHROUGHS:

QUANTUM COMPUTING

Faster Randomized Dynamical Decoupling (Ref. 2025-010)

A new (randomized) dynamical decoupling (DD) protocol that can improve the performance of any given existing (deterministic) DD methods, by introducing no more than two additional pulses. Specifically, they developed a novel framework that converts any given deterministic DD protocol into a randomized version that can significantly outperform the original deterministic approach. Additionally, they proved that the randomized protocol achieves a quadratic improvement over what was previously considered to be the optimal DD method. To rigorously evaluate the performance, they introduced new analytical methods suitable for analyzing higher-order DD protocols that might be of independent interest.

Benefits:

- Improves the performance of any existing deterministic DD protocol
- May inspire experimental implementations and improve performance of current quantum devices
- Both rigorous error analysis and numerical simulations are presented confirming that the randomized protocol can significantly improve many widely used DD protocols such as XY8 and Uhrig DD

Publication: Faster Randomized Dynamical Decoupling

Circuit-based Leakage Detection for Neutral Atom Quantum Computing (Ref. 2025-002)

Researchers at the University of New Mexico, in collaboration with researchers from the Sandia National Laboratory, have developed a novel, circuit-based leakage detection for atom-loss error in neutral atom quantum computers. The invention utilizes circuit-based leakage detection units (LDUs), which can detect the presence of the data atom and map that onto the 0-1 states of an ancilla qubit. The mapping process can be done without disturbing the information in the data qubit in case of no atom loss. The researchers proposed the implementation of SWAP-style LDUs and teleportation LDUs.

Benefits:

- This approach has unique advantages for neutral atom quantum hardware in that the data atom is automatically refilled in the case of leakage, providing savings on recompiling costs in the case of an atom loss event
- Provides a potential strategy for mid-circuit mitigation of atom heating and its resulting deleterious effects on atom loss and gate fidelity
- The LDUs can detect all three major leakage pathways (atom loss, Rydberg and hyperfine leakage)
- Provides a strategy for continuous reloading of a small computational array embedded in a large atom array by continually swapping hot atoms with cold ones

High-Performance Multi-Physics-Coupling-Enabled Brillouin Laser/System **(Ref. 2023-066)**

Proposed here is a new high-performance Brillouin laser system that is capable of very high bandwidth and resolution. The invention optimizes the Brillouin process by coupling photons, phonons, and electrons. The innovative device architecture covers two classes of devices: non-resonant for signal processing applications and resonant for narrow linewidth plasma-enhanced optomechanical transduction along with acoustoelectric (AE) amplification. The plasma enhancement (PE) increases the transduction efficiency from photons to phonons and reduces the threshold requirements for more efficient systems. Thus, PE-transduction can be applied to both non-resonant systems and resonant systems. The invention will offer a chip-scale, plasma force enhanced Brillouin silicon photonics system at the nanoscale, with the expected bandwidth exceeding 100GHz and with channel resolution as sharp as 1MHz.

Benefits:

- Offers Brillouin process optimization and improved etching precision
- Provides enhanced optomechanical transduction and enables acoustoelectric amplification
- Combines the advantages of the photonic and acoustic domains at the nanoscale to deliver revolutionary device performance
- Enables a platform capable of ultrabroad bandwidth and high channelization density with high filter quality and large delay that simultaneously exhibit high gain, low noise, and large transduction efficiencies

---

Fault Tolerant Quantum Computation in Spin Systems Using Cat Codes **(Ref. 2023-042)**

Researchers have developed a new quantum error-correcting code for spin systems. They have constructed a class of error-correcting spin-cat codes that protects the quantum information against dominant errors in the alkaline-earth atomic systems where quantum information in encoded in a nuclear spin, with multiple levels (a qudit). The dominant errors include dephasing and amplitude damping due to optical pumping when atoms absorb and emit photons. In addition, they have constructed a new universal set of gates that preserves the bias of the dominant errors in these atomic spin systems and enables fault-tolerant quantum computation using spin systems. In particular, a new design for a bias-preserving CNOT gate has been developed and has been used to perform measurement-free error correction. As a result, these codes offer a path to fault tolerance with fewer atoms by taking advantage of the extra available internal degrees of freedom in these atomic systems.

Benefits:

- New design of bias-preserving CNOT gate for atomic systems
- New design of measurement-free error correction procedure reduces the resources required to perform reliable computations in the presence of error

Intellectual Property: US 2024/0281695 A1

Semiconductor Vertical Spin Valves and Method for Their Production (Ref. 2021-068)

Researchers at the University of New Mexico and the University of Wisconsin-Madison have developed a vertical spin valve (VSV) based on semiconductor nanomembranes (NMs) engineered with arrays of screw dislocations. The unique symmetry of a screw dislocation generates a helical electric field and a magnetic field that interact with spin-polarized electrons by restricting any changes in spin polarization due to scattering between 0 and 90°. Spin-orbit-coupled electron location deep within the semiconductor bandgap also enables the prevention of hybridization between polarized and unpolarized electrons, resulting in an extended coherence time.

Benefits:

- Enables long spin coherence times
- Possibility to control spin texture
- Switches between high and low resistance states, by field or spin torque
- Holds the potential to provide amplification, along with switching functionalities
- Easy integration with traditional semiconductor technology(ies)
- Allows for vertical integration

Intellectual Property: 12,328,913

Quantum-Computing in a Scalable Photonic Platform (Ref. 2020-022)

Researchers from the University of New Mexico and the University of Arizona have developed an on-chip photonic platform to produce 3D continuous variable (CV) cluster states. The platform combines Kerr microcombs and CV quantum information, formulating a one-way quantum-computing architecture. Kerr nonlinearity is utilized with both time and frequency multiplexing to produce reconfigurable one, two, or three dimensional CV cluster states. The quantum-photonic platform’s ability to access a large number of spectral modes enables the scalability and robustness required to produce large-scale 3D CV cluster states. This platform can be readily implemented with silicon photonics, opening a promising avenue for fault-tolerant quantum computing at a large-scale.

Benefits:

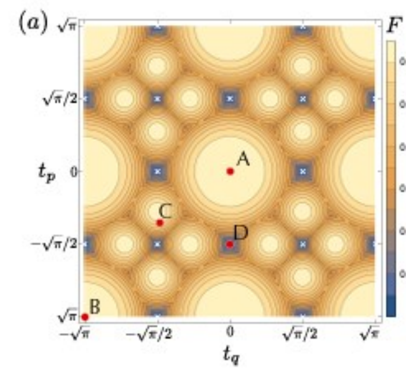
- One-way quantum computing architecture for mass producible, large-scale, high quality cluster states
- Access to a large number of spectral modes enabling the scalability and robustness required to produce large-scale 3D CV cluster states
- Reprogrammable to produce reconfigurable one, two, or three dimensional CV cluster states
- Readily implemented with silicon photonics

Publication: Quantum-Computing Architecture based on Large-Scale Multi-Dimensional Continuous-Variable Cluster States in a Scalable Photonic Platform

Intellectual Property: 12,254,381

Producing Magic States for Universal Quantum Computation using GKP Error Correction (Ref. 2019-085)

Researchers from the University of New Mexico and RMIT University have developed a method for producing continuous-variable magic states for fault-tolerant quantum computing. This specific invention describes a method for achieving all the necessary building blocks for quantum computation using a particular type of qubit. No non-Gaussian resources are required beyond GKP Pauli eigenstates, resolving issues related to current proposed methods that require additional non-Gaussian resources. The described method simplifies the technical requirements for universal, fault-tolerant quantum computing.



Benefits:

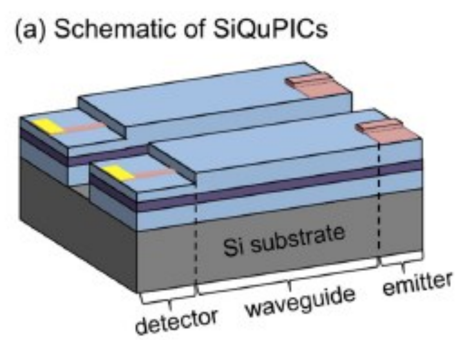
- Requires only one type of non-Gaussian state for fault-tolerant universal quantum computing
- Solves the problem of creating magic states
- Surpasses other known methods of producing continuous-variable magic states
- Provides a simple and convenient way of preparing magic states that are suitable for a type of quantum error correcting code made from a quantum harmonic oscillator

Publication: All-Gaussian Universality and Fault Tolerance with the Gottesman-Kitaev-Preskill Code

Intellectual Property: 12,254,382

Integrated Silicon Photonics Platforms for Scalable Quantum Systems (Ref. 2019-032)

Researchers from the University of New Mexico and the University of Rochester have developed and provided an integrated platform to implement novel devices for quantum communications. The integrated superconductor platform utilizes an emitter and photodetector for optimal quantum information technology on the same integrated chip. Each quantum application, whether communication, computing, metrology, sensing, etc., has its own requirements that form the basis of silicon quantum photonic integrated circuits. Individual devices such as single-photon sources, detectors, and dielectric waveguides have been largely uncharted in relation to their quantum network but could potentially transform quantum information technology.



Benefits:

- Silicon photonics platforms for scalable quantum systems
- Progress in technology related to the generation, manipulation, storage, propagation, and detection of photons for QuIP
- Used in development of large-scale systems

Quantum Information Processing using Entangled Neutral-Atom Quibits (Ref. 2017-048)

Researchers at the University of New Mexico and Sandia National Laboratories have developed a new, practical approach that can reliably produce entangled quantum state of an atomic ensemble using Rydberg-dressed blockade. Each atom of the atomic ensemble is loaded into a respective optical trap with the implementation of pump radiation. Every qubit is encoded inside the hyperfine sublevels of a neutral atom from the first atomic quantum state to a second atomic quantum state. By impinging a beam from, e.g., an off resonance Rydberg excitation laser onto the atoms, which have been placed at sufficiently short inter-atomic distances, they can produce the interactions between ground-state atoms that cause some transitions between the states of multiple-qubit basis to be blockaded. The atoms of the atomic ensemble are separated by more than a dipole-dipole interaction length.

Benefits:

- Creates an entangled state with one pathway for the Rydberg atom in a two-atom system
- 80% fidelity of generating Einstein-Podolsky-Rosen (EPR)
- Efficient way to generate entangled states with qubit transition pulse
- Can be extended to systems of three or more atoms

Intellectual Property: 9,934,469

TECHNOLOGY BREAKTHROUGHS:

QUANTUM DOTS

Method for Fabricating Plasmonic Quantum Dots and Related Nanostructures

(Ref. 2016-057)

A method for fabricating plasmonic quantum dots (PQD) as nonlinear optical materials for sensing applications, id described here. This technology will not only help enhance the electric fields in the center of the nanostructure, thus increasing the brightness of the nanoparticles, but will also chemically isolate the QDs from the tissue and significantly reduce the toxicity of such TPAF nanoparticles. This nanoparticle-based material has very high potential for nonlinear optical imaging applications, notably for two-photon absorption fluorescence-based deep tissue imaging.

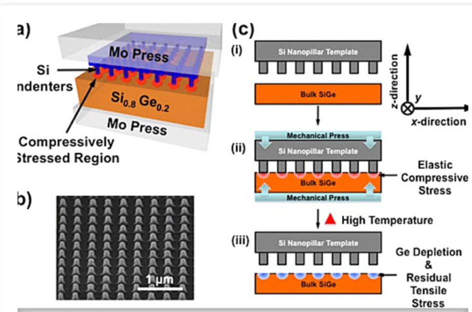
Benefits:

- Method for fabricating plasmonic quantum dots and related nanostructures
- Highly versatile composite material nanoparticle-based plasmonic nanosensors
- High spatial resolution (sub-100 nm)
- Potential use for ultraprecise pH sensing
- Potential for nonlinear optical imaging applications, notably for two-photon absorption fluorescence-based deep tissue imaging

Intellectual Property: 11,275,089

Large-Scale Patterning of Germanium Quantum Dots by Stress Transfer **(Ref. 2014-010)**

Researchers from the University of New Mexico and the University of Pennsylvania have developed a novel process to produce a 2D array of germanium (Ge) quantum dots on silicon-germanium (SiGe) substrates. The process involves reusable technology that has the potential to offer transformative cost-reductions in fabricating a well-defined 2D array of nanostructures. This technology allows for Ge growth to be steered in a well-defined nanoscale 2D array without forming dislocations, while requiring a high degree of uniformity across large areas.



(a) Schematic representation of assembly used to create patterned stress fields in a SiGe substrate. (b) SEM image of Si nanopillar array used to apply a patterned stress field to the SiGe substrate. (c) Steps in the stress transfer process: (i) place Si nanopillar indenter array on top of SiGe substrate, (ii) press the indenters against the substrate, and (iii) thermally anneal the stack under patterned stress field.

Benefits:

- Single, reusable mold keeps costs low
- Useful across many tech applications
- Even Ge growth across large areas

Intellectual Property: 9,373,547 / 9,666,431

Publication: Stress-directed compositional patterning of SiGe substrates for lateral quantum barrier manipulation

TECHNOLOGY BREAKTHROUGHS:

QUANTUM DEVICES

Actively-Controlled Fast-Switching Gas-Gap Thermal Switch (Ref. 2023-004)

A gas-gap thermal switch has been developed to achieve ultra-low temperature refrigeration with low 3He usage. Instead of moving helium gas in and out of the switch, thermal conductance has been changed by moving a thermally conductive element (the "shuttle") within the helium gas. This new thermal switch overcomes a key roadblock to the development of commercial Continuous Adiabatic Demagnetization Refrigeration (CADR) with constant-temperature stages. The design supports CADR with constant-temperature stages without an efficiency or cycle-time penalty and improves performance while simultaneously lowering the barrier to entry into CADR for commercial low-temperature vendors. As a result, this will facilitate the commercial development of CADR as a low-3He drop-in replacement for 3He-dilution refrigeration for wide application in Quantum Information Science and other fields.

Benefits:

- Improved thermodynamic efficiency and eliminates the need to heat a sorption pump
- Eliminates the need to pump helium, removing time-consuming uncertainty of attaining fast pump speeds
- Offers fast switching times from fully "on" to fully "off" of 1 second or less
- All of the individual elements have already been well-tested at low temperatures
- Strengthens American competitiveness in cryogenics

Device for Photon Statistic Measurement of a Pulsed Light Source (Ref. 2019-044)

A device has been developed that can distinguish the photon statistics of a given pulsed light source without coincidence counting and without using photon number resolving detectors. This novel method uses an asymmetrical beam splitter rather than a balanced 50:50 beam splitter. Experimental studies using the asymmetrical device confirm the possibility of determining photon statistics of light sources without coincidence counting and avoiding complications due to pulse overlaps from current detectors. This technique can distinguish the thermal light source from a coherent light source and simplify measurement, making the process of photon statistic measurement more cost-effective for a variety of applications.

Benefits:

- Does not require coincidence counting and single photon resolving detectors to determine the photon statistics of a light source
- Minimizes errors and uncertainties caused by current methods, while reducing overall cost

Publication: Photon statistics without coincidence counting using an unbalanced beam-splitter

Intellectual Property: 11,422,028

UNM RELATED PROGRAMS

Center for Quantum Information and Control (CQuIC)

The Center for Quantum Information and Control (CQuIC) (https://cquic.unm.edu) is an interdisciplinary research center located at the University of New Mexico in Albuquerque with activities across the departments of Physics & Astronomy, Electrical & Computer Engineering, and Chemistry & Chemical Biology.

Research at CQuIC is focused on Quantum Information Science, including quantum computation, quantum simulation and complexity, quantum control and measurement, quantum metrology, and quantum optics and communication.

Quantum New Mexico Institute

The Quantum New Mexico Institute (https://qnm.unm.edu) is a joint research entity that seeks to accomplish transformative, long-lasting breakthroughs in Quantum Information Science through the efforts of scientists from the Department of Physics and Astronomy at the University of New Mexico as well as Sandia National Laboratories.

The mission of QNM-I is to expand research & development and education as well as promote efforts to advance the local and regional quantum ecosystem to meet the nation's economic and national security goals.

Quantum Systems Accelerator

The center (https://quantumsystemsaccelerator.org) is one of five Department of Energy Quantum Information Science (QIS) led by Lawrence Berkeley National Laboratory (Berkeley Lab) that will forge the technological solutions needed to harness quantum information science for discoveries that benefit the world. It will also energize the nation's research community to ensure U.S. leadership in quantum R&D and accelerate the transfer of quantum technologies from the lab to the marketplace. Sandia National Laboratories is the lead partner of the center. Research Centers. QSA brings together scientists who are pioneers of many of today's quantum capabilities from the following institutions: Lawrence Berkeley National Laboratory, Sandia National Laboratories, University of Maryland, University of Colorado at Boulder, MIT Lincoln Laboratory, Caltech, Duke University, Harvard University, Massachusetts Institute of Technology, Tufts University, UC Berkeley, University of New Mexico, University of Southern California, UT Austin, and Canada's Université de Sherbrooke.

UNM RAINFOREST INNOVATIONS

As the technology-transfer and economic-development organization for the University of New Mexico, UNM Rainforest Innovations (http://innovations.unm.edu/) protects and commercializes technologies developed at the University of New Mexico (UNM) by filing patents and copyrights and transferring the technologies to the marketplace. We connect the business community (companies, entrepreneurs and investors) to these UNM technologies for licensing opportunities and the creation of startup companies.

UNM Rainforest Innovations has filed intellectual property on these exciting new technologies and is currently exploring commercialization options. For more information, please contact Alex Roerick, Innovation Manager for Physical Sciences & Engineering at aroerick@innovations.unm.edu

Visit our full list of available technologies, searchable by keyword or category, here: UNM Rainforest Innovations' technology portfolio.