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SMAQ project paves the way for optical tweezers for quantum excitation in the UV range

Qubits under Control: Scalable Technology for Quantum Computers through Spatial Light Modulators

The Fraunhofer Institute for Photonic Microsystems IPMS and the Max Planck Institute of Quantum Optics (MPQ) have achieved groundbreaking results in generating arbitrary light distributions. These findings are also relevant to atomic quantum computing. Spatial light modulators can be used to hold a large number of atoms in desired positions at the same time via laser beam. Localized in this way, they become switchable information carriers for quantum computers or for other applications in quantum metrology and quantum simulation, marking a major stride toward scalable quantum systems.

Quantum computers are considered the technology of the future when it comes to powerful computing systems. There are currently various technological methods of realizing systems like these, including superconducting circuits, photonic circuits and individual atomic qubits, such as neutral atoms and trapped ions. Neutral atoms in optical tweezers are a relatively new line of research, but one that is advancing rapidly compared to other technologies. In the Scalable Optical Modulators for Atomic Quantum Computers (SMAQ) project, which was realized as part of the Research Fab Microelectronics Germany (FMD) QNC Space, Fraunhofer IPMS and the Max Planck Institute of Quantum Optics have now achieved significant successes for the development of neutral atom or trapped-atom quantum computers.

Lasers as quantum exciters

Quantum computers based on charged or neutral atomic qubits offer a wide array of advantages over alternative technologies. They permit intrinsically high quality in the individual qubits — the charge carriers in the computer system — and thus achieve excellent coherence times and gate quality. For neutral atoms to become qubits, they need to be manipulated with high-precision lasers in their quantum states. Strontium atoms are among those used to generate qubits in atomic quantum computers. These atoms are manipulated in the UV range, as important electronic transitions that can be used to excite their quantum states can only be achieved in the ultraviolet spectral range. The Max Planck Institute of Quantum Optics has been researching how to arrange and address neutral atoms for some time now. The hardware needed for spatial modulation

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of the UV rays that are required is still in development. Currently, there is a lack of scalable and sufficiently precise solutions that can be used to excite qubits individually. Researchers working on the project have now demonstrated that high-quality optical dot grids can be realized in the relevant UV wavelength range with spatial light modulators (SLMs) based on piston mirror arrays.

Fraunhofer IPMS has special expertise in these kinds of arrays. In an experiment led by the Max Planck Institute of Quantum Optics, the strontium atoms used to generate qubits are laser-cooled and trapped in optical dot grids. The joint project brought together the partners' complementary expertise in a bid to advance into new realms of atomic quantum computing. To this end, Fraunhofer IPMS further developed a micromirror-based SLM that can be used to generate programmable and highly precise patterns in the nanometer range. The phase patterns generated can then be converted into any kind of laser beam schema using suitable optics. As part of the project, a relevant element was provided to the Max Planck Institute of Quantum Optics for testing. Its performance was demonstrated across all fields.

Future work will be geared toward trapping the tiny atoms in the focal points of the laser beams and holding them in certain positions. Laser beams acting in this way are known as "optical tweezers." The atoms' internal quantum states are then manipulated using high-precision pulses to perform quantum logic operations for quantum calculations.

Michael Wagner from Fraunhofer IPMS says of the successful project: "Our SLM systems enable light modulation up to the deep UV range. Micromirror technology offers a wide range of advantages over liquid crystal-based light modulators, such as UV compatibility, higher modulation speeds up to the megahertz range and polarization-independent work." Alongside Fraunhofer IPMS demonstrating that SLMs are suitable for quantum optical experiments in the UV range and the Max Planck Institute successfully qualifying the technology for the experimental set-up, the project also focused on evaluating the accuracy of the phase modulation. Phase control in a range significantly below one one-hundredth of a wavelength was demonstrated, meeting the most stringent requirements that apply to the quality of optical tweezers.

The next step on the way to a quantum system

The use of micromirror-based SLMs for pattern generation and qubit control opens up a whole new dimension in relation to accuracy and scalability. The demonstrator developed and the project results are key parameters for targeted further development of the SLM technology for applications in the quantum field. Going forward, they may serve as a sound basis for realizing an apparatus for addressing the atoms. One of the next goals is to develop SLMs that enable parallel generation of several thousand fo-

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cused laser beams in the ultraviolet spectral range. Increasing the system's speed is another area of focus. The 1 kHz that has been achieved at present is merely a starting value for significantly faster future modulators.

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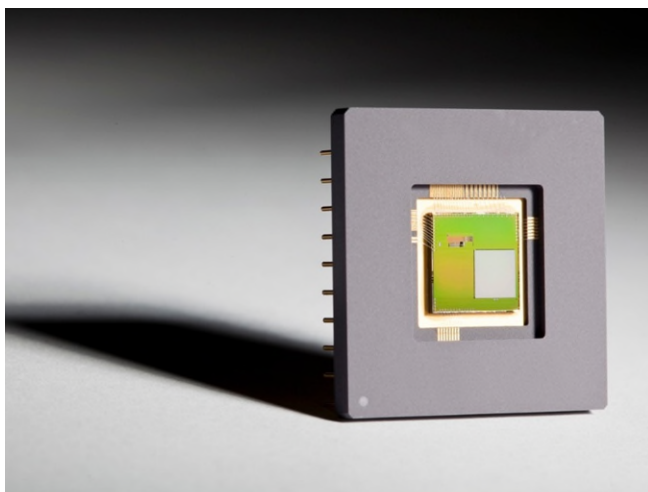


Fig. 1 SLM component for phase modulation based on piston mirror arrays

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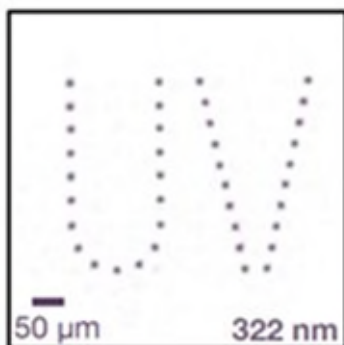


Fig. 2 Experimentally generated dot pattern in the UV range (322 nm), suitable for optical tweezers

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