Solid-state emitters

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Taming photons on a chip

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The integration of a quantum emitter-embedded metasurface (QEMS) with a microelectromechanical system (MEMS)-actuated cavity enables ångstrom-level wavelength tuning and dynamic polarization-resolved emission. The platform provides a design paradigm for reconfigurable solid-state photon sources.

Solid-state quantum emitters, such as nitrogen-vacancy centres in nanodiamonds, have long been the unruly rock stars of photonics: brilliant yet notoriously difficult to control[1–3]. Like a virtuoso playing every note at once, nanodiamonds containing nitrogen-vacancy centres produce broadband emission with random polarization and direction[1,4]. Taming this photonic cacophony into coherent, tuneable and directional photon streams remains a central challenge in quantum photonics.

Recent advances have made headway through carefully engineered structures, including nanoantennas, dielectric waveguides and optical cavities to improve photon extraction and directionality[5]. Particularly promising are metasurfaces[6,7], which have demonstrated remarkable capabilities in tailoring emission characteristics, including phase, amplitude and polarization[5]. However, real-time reconfigurability is still challenging to achieve for solid-state photon sources. Most approaches yield static devices, offering no post-fabrication control over emission properties, especially within compact, room-temperature-compatible systems[5].

Now, writing in *Nature Photonics*, Kan and colleagues present an elegant solution to this longstanding challenge by introducing a dynamic MEMS–QEMS photon source (Fig. 1)[8]. Their modular platform integrates QEMS with a MEMS-tuneable Fabry–Pérot microcavity, achieving ångstrom-level spectral tuning and dynamic polarization switching under ambient conditions. The resulting device functions as a reconfigurable solid-state photon source, sculpting emission spectrum, directionality and polarization of photons in real time on a chip-scale platform.

The QEMS serves as an interface between quantum emitters and free-space radiation. By placing the nanodiamonds containing nitrogen-vacancy centres in the middle of a bull's-eye grating made of hydrogen silsesquioxane, and illuminating the material with a radially polarized 532-nm laser, the authors achieve efficient surface plasmon polariton excitation. This allows the metasurface to transform the otherwise broadband, randomly polarized emission into collimated, polarization-controlled beams[8]. Dynamic tuneability is achieved via a MEMS-actuated mirror that forms a variable-length microcavity with a fixed dielectric Bragg reflector (Fig. 1). Piezoelectric actuation enables precise control of the cavity length, allowing selective enhancement of target wavelengths. The system offers a tuning resolution of 0.8 Å with a voltage step of 50 mV, while preserving spectral stability and spatial

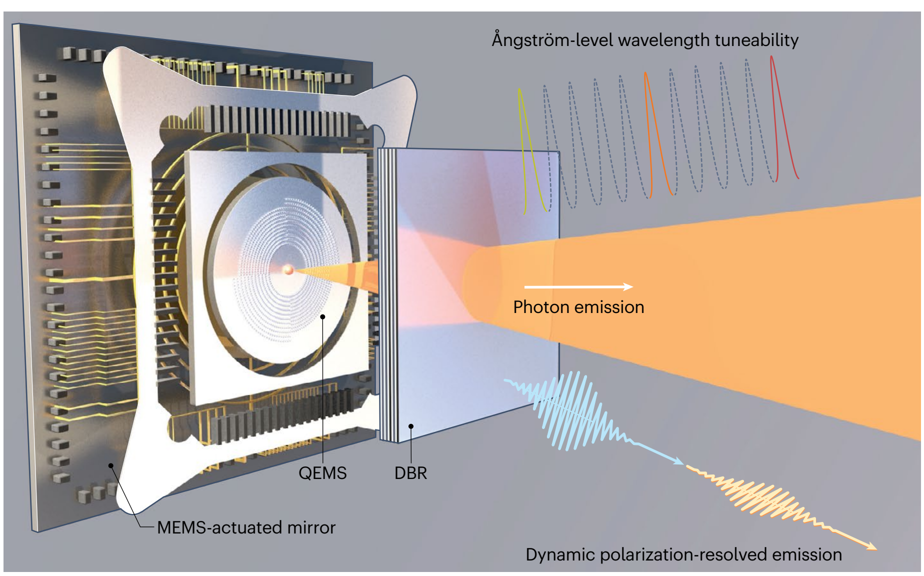

Fig. 1 | Dynamic microelectromechanical system (MEMS)–quantum emitter-embedded metasurface (QEMS) photon source. A QEMS is integrated with a MEMS-actuated mirror and a dielectric Bragg reflector (DBR) to form a tuneable Fabry–Pérot microcavity. This platform enables ångstrom-level wavelength tuning and real-time polarization control of photon emission. The QEMS reshapes the emission profile from the embedded quantum emitter, and the MEMS actuation adjusts the cavity length to selectively enhance specific spectral and polarization states, yielding a compact, versatile source of reconfigurable solid-state photons on a chip.

mode quality. The emission bandwidth of nitrogen vacancies is narrowed from around 100 nm to 3.7 nm, corresponding to a quality factor of about 180 at 670 nm. Beyond spectral narrowing, the device supports continuous and reversible tuning across a selected spectral window, a substantial improvement over traditional emitter–cavity systems.

Equally significant is the ability to control polarization. The authors implement polarization multiplexing using spatially separated metasurface regions, composed of anisotropic dielectric bricks. One region emits y-polarized light centred at 650 nm, while another emits x-polarized light at 700 nm. Both are integrated into the same cavity structure and addressed via MEMS actuation. By adjusting the cavity length, the system selectively enhances emission from one region or the other, enabling fast, voltage-controlled polarization switching. Switching times are below one millisecond, making the platform well suited for high-speed modulation in quantum applications. Crucially, this dual degree of control over wavelength and polarization is realized using a single MEMS actuator, yielding a compact, complementary metal–oxide–semiconductor (CMOS)-compatible source of reconfigurable quantum light. The fabrication process employs standard nanofabrication techniques and is compatible with integration of electronic components, facilitating scalable deployment.

The implications of this work are broad. Dynamically tuneable solid-state photon sources could advance quantum key distribution, integrated photonic quantum computing, and reconfigurable optical neural networks[1]. Independent control over emission parameters further enables structured light encoding, potentially boosting data capacity in both classical and quantum optical channels[1]. The modular QEMS design is adaptable to a range of quantum emitters, including semiconductor quantum dots, perovskites, two-dimensional materials and rare-Earth ions[1,3], paving the way for hybrid photonic devices tailored to specific applications.

Despite these advances, challenges remain. Optical losses introduced by the metallic mirror limit overall quantum efficiency[5]. Future implementations could explore all-dielectric reflectors or hybrid photonic-plasmonic designs to mitigate these losses without compromising tuneability[9]. In parallel, the mechanical stability and fatigue resistance of the MEMS actuator under extended, high-speed operation must be thoroughly evaluated to ensure long-term reliability. Full system integration will also require co-packaging with control electronics as well as robust thermal and environmental protection.

Nonetheless, the work by Kan and colleagues marks an important advance: from fixed-function quantum emitters to programmable photon sources. This transition echoes the evolution of electronics, where rigid logic circuits gave way to field-programmable devices. Quantum photonics is now at a similar transition point. As metasurfaces evolve into active, multifunctional components[5], and as MEMS systems gain precision and scalability[10], we may soon see the emergence of quantum light engines, devices that not only emit single photons, but also sculpt their properties in spectrum, polarization, space and time, all on demand.

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Competing interests

The authors declare no competing interests.