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Ultracompact entangled photon sources based on 2D semiconductors

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Abstract: Here we realize ultracompact entangled photon sources by periodically poling 2D semiconductors (3R-MoS_2), demonstrating quasi-phase-matched up- and down-conversion over micron-thick pathlengths.

Nonlinear optics lies at the heart of classical and quantum light generation. Conventional nonlinear crystals have moderate second-order nonlinearities ($\chi^{(2)}$ = 1-30 pm/V) but can reach high nonlinear conversion efficiencies due to their large thickness (millimeter/centimeter). However, such macroscopic thickness limits further technology development and on-chip integration. The miniaturization paradigm, which has dominated the world of electronics, is now shifting to the field of photonics, e.g., all-optical integrated circuits, essential for energy-efficient processes. The miniaturization problem manifests as a trade-off between efficiency and size.

Non-centrosymmetric 2D semiconductors, e.g., 3R-MoS_2, possess large nonlinearity ($\chi^{(2)}$~100 pm/V) and easy system integration, holding great promise for frequency conversion over ultrathin pathlengths[1], entangled photon pair generation[2], and efficiency scaling with thickness of nonlinear processes like second harmonic generation (SHG)[3]. However, upon increasing the crystal thickness, the wave vector mismatch (Δk) limits the maximum SHG that can be emitted, and it defines the thickness at which such maximum SHG can be generated: the so-called coherence length $L_c=\pi/\Delta k$. At L_c the maximum conversion efficiency of 3R-MoS_2 excited around telecom wavelengths is ~10^{-6}. Pushing towards higher conversion efficiencies, comparable to bulk nonlinear crystals (i.e., 10^{-2}-10^{-1}), requires phase-matching the nonlinear interactions.

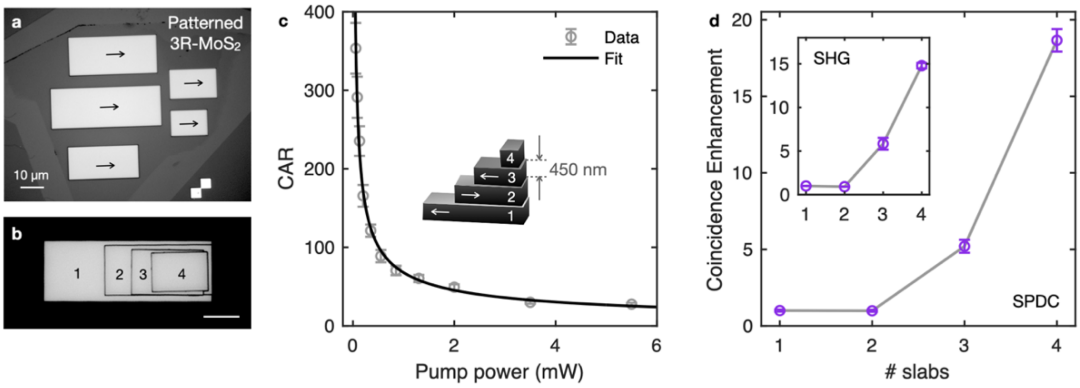

Fig. 1. Patterned 3R-MoS_2 flake (a) and PPTMD after stacking (b). Coincidence-to-accidental-ratio (CAR) of a PPTMD with slab thickness 450 nm (c). Coincidence enhancement at 1550 nm and corresponding SHG efficiency enhancement at 775 nm (c), demonstrating quasi-phase matching at the fundamental wavelength 1550 nm (d).

Here we realize periodically poled transition metal dichalcogenides (PPTMDs)[4], using 3R-MoS_2 (Fig.1a-b), to achieve quasi-phase matched up- and down-conversion. We select a large flake with thickness close to the L_c, we pattern it using electron beam lithography and reactive ion etching into smaller portions with identical thickness and dipole orientation (→) (Fig. 1a), and we flip the sign of the nonlinearity by stacking consecutive slabs with opposite dipole orientations (Fig.1b). Due to its large nonlinearity, we achieve macroscopic conversion efficiency (0.01%-0.1%) of SHG over a microscopic thickness of only 3 µm (just three poling periods). Further, we report the generation of entangled photon pairs at telecom wavelengths reaching large coincidence-to-accidental-ratio (CAR) (Fig.1c) via quasi-phase-matched spontaneous parametric down-conversion (SPDC) (Fig.1d), outperforming any existing van der Waals-based SPDC source by nearly 2 orders of magnitude.

PPTMDs open the new and unexplored field of phase-matched nonlinear optics with microscopic van der Waals periodic poling, providing macroscopic nonlinear conversion efficiencies over microscopic thicknesses. As on-chip integrable, programmable, microscopic, entangled photon sources, PPTMDs unlock new applications that require simple, ultracompact technologies for integrated quantum circuitry and sensing[4].

References

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