Supplementary Materials for

Room-temperature on-chip orbital angular momentum single-photon sources

Cuo Wu, Shailesh Kumar, Yinhui Kan, Danylo Komisar, Zhiming Wang, Sergey I. Bozhevolnyi, Fei Ding*

*Corresponding author. Email: feid@mci.sdu.dk

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Note 1: Theoretical investigation of the far-field radiation

For the cylindrically diverging surface plasmon polaritons (SPPs) excited by a z-oriented electric dipole, the in-plane radial electric field will be dominating and contribute to the photon generation. After propagating over a spatially varied distance, the SPPs in-plane components interact with the Archimedean spiral grating and be subsequently re-radiated into outgoing photons carrying a spiral phase profile of $m\phi$, where $m$ is the arm number and $\phi$ is the azimuthal angle. Importantly, owing to the scattering effect of the spiral ridges, the radiation is also radially polarized (RP). Thus, the secondary sources on the Archimedean spiral grating (e.g., near field components) that contributes to the far-field radiation can be expressed as

$$E_{spp}(r, \phi, 0) = \frac{\exp(ik_{spp}r)}{\sqrt{r}} \left(\frac{\cos \varphi}{\sin \varphi}\right)$$  \hspace{1cm} (S1)

where $(r, \phi, 0)$ indicates the cylindrical coordinate in the near-field and $k_{spp}$ is the SPP propagation constant. Consequently, the electric field in the far-field can be integrated as

$$E_{ff}(\rho, \varphi_f, z_f) \sim \int_0^\infty \int_0^{2\pi} E_{spp}(r, \phi, 0) e^{-i \frac{2\pi}{\lambda_0 \rho_f r} \cos(\varphi - \varphi_f)} d\varphi \, rd\rho$$  \hspace{1cm} (S2)

where $(\rho, \varphi_f, z_f)$ is the observation point in the far-field and $\lambda_0$ is the free-space radiation wavelength. For simplicity, we discuss the ideal case and consider the uniform amplitude distribution for all secondary sources by neglecting the radius-dependent propagation loss of SPPs. In the calculation, the amplitude of the considered near-field is approximated as the uniform distribution decaying at beam waist only to avoid diffraction on aperture boundaries

$$E_{spp}(r, \phi) = \left(\frac{\cos \varphi}{\sin \varphi}\right) e^{im\varphi} e^{-\frac{r^2}{w₀^2}}$$  \hspace{1cm} (S3)

where $w₀ = 5\lambda_0/n_{spp}$ is the beam waist of the RP Gaussian beam, and $n_{spp} = \frac{\lambda_0}{2\pi} \text{Re}(k_{spp})$ is the effective SPP mode index. Figure S1 shows the analytical far-field intensity profiles and phase windings in the circularly polarized (CP) basis, where two CP beams carrying different orbital angular momentum (OAM) are clearly observed. After further approximation, the far-field radiation can be decomposed into the $x$- and $y$-components in the Cartesian coordinate

$$\begin{bmatrix} E_{ffx}(\rho, \varphi_f, z_f) \\ E_{ffy}(\rho, \varphi_f, z_f) \end{bmatrix} \propto J_{|m|+1} \left( \frac{1}{i} \right) e^{i(m+1)\varphi_f} - J_{|m|-1} \left( \frac{1}{i} \right) e^{i(m-1)\varphi_f}$$  \hspace{1cm} (S4)

where $J_{|m|+1} = J_{|m|+1} \left( -i \frac{2\pi r_0 \rho}{\lambda_0 \rho_f} \right)$ is the $(|m| + 1)^{th}$ Bessel function of the first kind. Therefore, the outgoing photon is a superposition of the right circularly polarized [RCP, $\frac{1}{\sqrt{2}} (\frac{1}{i})$] and left circularly polarized [LCP, $\frac{1}{\sqrt{2}} (\frac{1}{i})$] OAM beams with topological charges of $\ell_R = m + 1$ and $\ell_L = m - 1$, respectively.
Note 2: Collection efficiency, quantum efficiency, and decay rate contributions from different channels

After interaction with Archimedean spiral gratings, the diverging SPPs coupled from quantum emitter (QE) radiation are effectively scattered into well-collimated outgoing photons. Therefore, the energy flows are dominantly ejected from hydrogen silsesquioxane (HSQ) spiral gratings (fig. S4). Compared to the bare SiO$_2$-Ag substrate where the far-field radiation can be rarely observed (fig. S5A), the spiral gratings could direct and concentrate the intensities around the center in Fourier space (fig. S5, B to D), thereby boosting the collection efficiency. To quantitatively show the collimation capability, we simulated the collection efficiency as a function of the numerical aperture (NA) of an objective by integrating the far-field radiation

$$CE_{NA} = \frac{\int_{0}^{2\pi} \int_{0}^{\sin^{-1} NA} E_{ff}(\theta, \phi) \sin(\theta) d\theta d\phi}{\int_{0}^{2\pi} \int_{0}^{\pi/2} E_{ff}(\theta, \phi) \sin(\theta) d\theta d\phi}$$ (S5)

As shown in fig. S6, the simulated collection efficiency with a NA of 0.9 exceeds 97% even for the most divergent LCP OAM light achieved with the five-armed spiral. If the NA is reduced to 0.65, the high collection efficiency is still maintained, which is larger than 78%. Besides the collection efficiency, the quantum efficiency $\eta_{QE}$, defined as the ratio of the far-field radiation power collected by the objective over total power generated by the dipole in the OAM source, has been calculated. With a NA of 0.9, the quantum efficiency is $\eta_{QE} \approx 47.2\%$.

In our configuration, the total decay rate $\gamma_{rad}$ of the QE is increased to $\sim 3.7 \gamma_0$, where $\gamma_0$ is the spontaneous decay rate of the QE in the vacuum. Specifically, the total decay rate contains contributions from three decay paths (fig. S7): direct radiation to free space ($\eta_{rad}$), excitation of SPPs ($\eta_{spp}$), and nonradiative decay ($\eta_{nr}$), where $\eta_{rad}$, $\eta_{spp}$, and $\eta_{nr}$ are the coupling efficiencies into three different channels, which are defined by normalizing the corresponding power to the emitted total power. As such, we have $\eta_{spp} + \eta_{rad} + \eta_{nr} = 1$ due to energy conservation. To quantify the coupling efficiency into SPPs, we assume that the direct free-space radiation is only slightly affected by the spiral grating and calculate the radiative efficiency $\eta_{rad0}$ of the QE-SiO$_2$-Ag configuration without any spirals by integrating the time-averaging far-field Poynting vector with a NA of 0.9 in the upper boundary and diving by the mediated total power, which is $\sim 17.2\%$. Then we analyzed our system and integrated the power leaving the near-field region (solid box in fig. S7) of the QE, which accounts for both the SPPs and radiative channels (26). After calculation, the coupling efficiencies into SPPs and nonradiative channels are found to be $\sim 78.4\%$ and $\sim 4.4\%$, respectively. After excitation, the SPPs propagate on the SiO$_2$-Ag substrate, interact with spiral gratings, and finally are scattered into well-collimated outgoing photons. Therefore, the SPP dissipation includes three parts: the absorption loss from plasmon ($\eta_{abs,spp}$), the scattering efficiency by spiral grating ($\eta_{sca}$), and the SPP residual ($\eta_{res}$), which have been quantified by selectively integrated the energy flux of SPPs on different planes (26) and summarized in Table S1. Here it should be noted that the quantum efficiency $\eta_{QE}$ can be slightly increased to 49.7% if the number of grating periods is increased from 8 to 12. Additionally, we should stress here that the quantum efficiency could be further increased to as high as $\sim 84.5\%$ by using single-crystalline ultralow-loss Ag and HSQ ridges with enhanced scattering efficiency, which however distorts the far-field distribution of the doughnut shape (fig. S8 and Table S2). To realize well-distributed OAM beams, each winding should contribute properly to the far-field radiation with moderate scattering capabilities.
Note 3: The degree of circular polarization of the far-field radiation
The degree of circular polarization, corresponding to the Stokes parameter $S_3$, can be calculated to clarify the spatially dependent state of polarization, which is depicted as

$$S_3 = \frac{-2i \text{Im}[E_{ffx}(k_x, k_y)E_{ffy}(k_x, k_y)^*]}{|E_{ffx}(k_x, k_y)|^2 + |E_{ffy}(k_x, k_y)|^2 + |E_{ffz}(k_x, k_y)|^2}$$  \hspace{1cm} (S6)

where $E_{ff}(k_x, k_y)$ ($i = x, y, z$) is the electric field component in the far-field with $(k_x, k_y) = (\sin \theta \cos \phi, \sin \theta \sin \phi)$. The uniform distribution of $S_3$ shows the linearly polarized emission from a dipole on the bare substrate without HSQ spirals (fig. S9A). With counterclockwise (CCW) spirals, $S_3$ becomes inhomogeneous with the paraxial red regions denoting the right circular polarization and the surrounding blue regions indicating the left circular polarization with higher topological charges. We can observe the red intense lobes (fig. S9, B to D) are 1, 3, and 5, respectively, which is directly related to the spiral arm number of $m = -1, -3, -5$. Since SPPs propagate with distance-dependent exponential decay along the spiral routine, the spiral head and tail experience slightly different SPP amplitudes, which produces these lopes in the far-field region. Besides, we notice that the Stokes parameter $S_3$ of the LCP component can’t be exactly $-1$ because of the spatial overlap between RCP and LCP beams in the outer area. To understand the transition between RCP and LCP polarization states, we evaluate the spatial overlap between these two states with different topological charges by introducing intensity overlap

$$\text{Overlap} = \frac{\iint |E_{ffx}(k_x, k_y)||E_{ffy}(k_x, k_y)|^2 \, dk \, dx \, dy}{\iint |E_{ffx}(k_x, k_y)|^2 \, dk \, dx \, dy \cdot \iint |E_{ffy}(k_x, k_y)|^2 \, dk \, dx \, dy}$$  \hspace{1cm} (S7)

As shown in fig. S10, the intensity overlap between these two states increases with more spiral arms. Due to the spread of OAM beams, RCP and LCP components can’t be fully separated, resulting in the spatial overlap, and therefore decreasing the degree of circular polarization of LCP beam with larger topological charges.

Note 4: Mode purities
Interferometry (e.g., Michelson interferometry) is the main approach to directly identifying the topological charges of OAM beams through forked fringes (53, 54). However, this method is only feasible for light sources with long enough coherence lengths, such as lasers, which allows enough space for displacing two optical paths. For the spontaneous emission from nano-diamonds (NDs) containing individual nitrogen-vacancy (NV) centers (ND-NVs), it’s also worth to check whether interference pattern can be formed when the two beams are properly displaced. However, due to the limited coherence length (~ 20 µm), it is challenging to produce an interference pattern with a conventional Michelson interferometer. Therefore, we modified the Michelson interferometer setup with two homemade mirrors (fig. S18). The two mirrors were made with arbitrary specific patterns capable of simultaneously focusing and reflecting the source. Thus, the tightly close position between one fixed mirror and one tilting mirror which is the condition for interference of spontaneous emission can be feasibly aligned via a 20X objective. The two overlapped image planes with specific patterns reflecting from two homemade mirrors were projected on CCD camera while illuminating with a lamp. These two focused image planes with specific patterns are identical positions of two homemade mirrors in front of small size BS. To align the setup, a 670 nm wavelength light source with a 20 nm bandwidth was selected from a supercontinuum laser combined with an acousto-optic tunable filter (NKT, SuperK EXTREME/FIANIUM) to mimic the emission from ND-NVs. Flipping the flip mirror to 670 nm reference light and the dichroic
mirror to the beam splitter, two Fourier planes reflecting from the two homemade mirrors were then projected and interfere in the CCD camera with slightly tilting the homemade mirror. In this way, the positions of two homemade mirrors are exactly the interfered positions for the spontaneous emission from the ND. As shown in fig. S19A, by tilting one of the homemade mirrors, the displacement between two self-interference beams increases and the interference disappears. However, the self-interference patterns of the RCP and LCP components have no fork-features (fig. S19, B and C), which is ascribed to insufficient displacement. Due to the low coherence length of ND-NVs, the displacement cannot be further increased to observe the fork-features. We note that for a different tilt angle between the two mirrors, the displacement needed would be different as the fringe spacing is shrunken.

To verify the OAM emission, we have projected the decomposed RCP and LCP components to a spatial light modulator (SLM). Without mounting the half-wave plate (HWP) in the optical setup (fig. S20), the RCP and LCP beams were first converted to vertically polarized beams by the quarter-wave plate (QWP). The vertically polarized beam was then projected to a SLM encoded with different topological charges functioning as the OAM basis. The topological charge of the OAM-carrying single photon emitter can be determined by varying the order of the phase pattern loaded onto the SLM (fig. S21). Additionally, the OAM mode purity can be measured, which is defined as the relative central intensity of the beam after demodulation by the SLM with an opposite topological charge. The measured mode purities of the decomposed RCP and LCP components are found to be 66.6% and 61.0%, respectively, which are considerable smaller than the simulated values of 97.8% and 96.6% (fig. S22).

Note 5: Quantum state tomography (QST)

The optical setup in fig. S18 can also be used for QST of the entangled state by conducting 16 projection measurements with different polarization and OAM basis through the QWP, HWP, linear polarizer (LP) and SLM. In our device, the Bell state can be expressed as $|\psi\rangle = \frac{1}{\sqrt{2}} (|R\rangle|\ell_0 = 0\rangle + e^{i\delta}|L\rangle|\ell = -2\rangle)$, where $\delta$ represents the uncertain phase difference between two entangled states of $|R\rangle|\ell_0 = 0\rangle$ and $|L\rangle|\ell = -2\rangle$ before conducting QST. To evaluate the equivalence between target ($\rho_t$) and reconstructed ($\rho_r$) matrices, the fidelity needs to be calculated as (55)

$$F(\rho_t, \rho_r) = \left| \text{Tr} \left( \sqrt{\rho_t} \sqrt{\rho_r} \sqrt{\rho_t} \right) \right|^2$$

Generally, to perform full measurements of quantum tomographic projection, $4^n$ operators are needed in a $n$-qubit system. Then the density matrix can be reconstructed and estimated by Maximum Likelihood method to find physical states with measured intensities by ensemble of all qubit states (42). For our device, $|R\rangle$ and $|L\rangle$ are considered as the spin angular momentum (SAM) basis while $|\ell = 0\rangle$ and $|\ell = -2\rangle$ are considered as the OAM basis. After superpositions of SAM and OAM basis, we get the following states: $|H\rangle = (|R\rangle + |L\rangle)/\sqrt{2}$, $|D\rangle = (|R\rangle - i|L\rangle)/\sqrt{2}$, $|+\rangle = (|\ell = 0\rangle + |\ell = -2\rangle)/\sqrt{2}$ and $|-i\rangle = (|\ell = 0\rangle - i|\ell = -2\rangle)/\sqrt{2}$. Hence, a complete set of operators for 16 tomographic measurements (Table S3) represented by $\hat{\nu}_i \otimes \hat{\mu}_j$ ($i,j = 1, 2, 3, 4$), are given as following

$$\hat{\nu}_1 = |R\rangle\langle R|$$
$$\hat{\nu}_2 = |L\rangle\langle L|$$

($S9$)
\[ \hat{\nu}_3 = |H\rangle \langle H| = \frac{1}{2} (|R\rangle + |L\rangle)(|R\rangle + |L\rangle)^\dagger \]  
(S11)

\[ \hat{\nu}_4 = |D\rangle \langle D| = \frac{1}{2} (|R\rangle - i|L\rangle)(|R\rangle - i|L\rangle)^\dagger \]  
(S12)

\[ \hat{\mu}_1 = |\ell = 0\rangle \langle \ell = 0| \]  
(S13)

\[ \hat{\mu}_2 = |\ell = -2\rangle \langle \ell = -2| \]  
(S14)

\[ \hat{\mu}_3 = |\rangle \langle \rangle = \frac{1}{2} (|\ell = 0\rangle + |\ell = -2\rangle)(|\ell = 0\rangle + |\ell = -2\rangle)^\dagger \]  
(S15)

\[ \hat{\mu}_4 = |\rangle \langle \rangle = \frac{1}{2} (|\ell = 0\rangle - i|\ell = -2\rangle)(|\ell = 0\rangle - i|\ell = -2\rangle)^\dagger \]  
(S16)

**Note 6: Impact of the ND-NV location on the performance**

Using numerical simulation, we verified that the OAM single-photon source is sufficiently robust with respect to the fabrication induced displacement of the ND-NV location at the 20-nm-scale, which is a typical level of accuracy that can be implemented with the fabrication based on standard electron-beam lithography. It is seen that the considered offset does not noticeably change the radiation pattern, the collection efficiency, and the mode purity, although the beams are slightly shifted from the center (fig. S23).
Fig. S1. Analytically calculated (A and C) far-field intensities and (B and D) phase windings.
Fig. S2. Impact of the SiO₂ spacer thickness $t_s$ on the SPP excitation. Impact of the SiO₂ spacer thickness $t_s$ on the decay rates (A and B), propagation length of SPP (C), and SPP mode index (D). To simulate the decay rates of different channels, a $z$-oriented electric dipole was placed 30 nm away from a bare SiO₂-Ag substrate. $\gamma_{\text{tot}}$, $\gamma_{\text{rad}}$, $\gamma_{\text{SPP}}$, and $\gamma_{\text{nr}}$ are the total decay rate and decay rates into free-space radiation, SPPs, and nonradiative channels, respectively. $\gamma_0$ is the spontaneous decay rate of the dipole in the vacuum.
Fig. S3. Calculated and simulated CP rates and topological charges with different arms. (A) Analytically calculated (dashed line) and numerically simulated (circles) CP rates of RCP (blue) and LCP (red) components as a function of the arm number $m$. The CP rate is defined as the intensity fraction of the CP component to the total field. (B) Simulated topological charges of RCP and LCP beams as a function of the arm number $m$. Note that LCP components have larger topological charges requiring progressively larger near-field supports, i.e., outcoupling structures, in order to match RCP components in the outcoupling efficiency.
Fig. S4. Numerically simulated energy flow (Poynting vector $P_z$) superimposed with designed HSQ spiral gratings with arm number of $m = -1, -3$ and $-5$ from left to right, respectively.
Fig. S5. Simulated far-field distributions. Numerically simulated far-field intensity distributions for the configurations without any structure (A) and with spiral gratings of arm number $m = -1$ (B), $-3$ (C) and $-5$ (D), respectively. All the intensities are normalized to that of the one-armed spiral structure.
Fig. S6. **Simulated collection efficiency.** Numerically simulated collection efficiency as a function of the NA for both RCP (A) and LCP (B) beams generated by spiral gratings with different arm numbers. For each case, the collection efficiency is normalized to its maximum value.
Fig. S7. Schematic of calculating coupling efficiencies of different channels for the designed one-armed OAM source. All the coupling efficiencies are defined by normalizing the corresponding power to the total power mediate by the QE coupled to the one-armed spiral grating.
Table S1. Calculated coupling efficiencies of different channels for the designed one-armed OAM single-photon source.

| Channel               | Parameter     | Efficiency |
|-----------------------|---------------|------------|
| Total                 | $\eta_{\text{tot}}$ | 100%       |
| SPPs                  | $\eta_{\text{spp}}$ | 78.4%      |
| Direct radiation      | $\eta_{\text{rad}}$ | 17.2%      |
| Nonradiative decay    | $\eta_{\text{nr}}$ | 4.4%       |
| Near-field integration| $\eta_{\text{nf\_surface}}$ | 95.6%      |
| Quantum efficiency    | $\eta_{\text{QE}}$  | 47.2%      |
| Spiral scattering     | $\eta_{\text{sca}}$ | 30.0%      |
| SPP absorption        | $\eta_{\text{abs\_spp}}$ | 13.5%      |
| SPP residual          | $\eta_{\text{res}}$ | 34.9%      |
Fig. S8. Simulation of the OAM photon source with a higher quantum efficiency by using single-crystalline ultralow-loss Ag. (A) Schematic of the optimized one-armed spiral grating with a quantum efficiency of \( \sim 84.5\% \). The starting radius is \( r_0 = 520 \text{ nm} \), and the number of grating periods is \( N = 12 \). The SPP wavelength is calculated to be 516 nm with a filling ratio of 0.64. (B) Numerically simulated quantum efficiency as a function of wavelength. (C) Decomposed far-field RCP and LCP intensity profiles and the corresponding phase windings.
Table S2. Calculated coupling efficiencies of different channels for the OAM single-photon source with a higher quantum efficiency in Fig. S8.

| Channel          | Parameter | Efficiency |
|------------------|-----------|------------|
| Total            | $\eta_{\text{tot}}$ | 100%       |
| SPPs             | $\eta_{\text{spp}}$ | 79.1%      |
| Direct radiation | $\eta_{\text{rad}}$ | 19.3%      |
| Nonradiative decay | $\eta_{\text{nr}}$ | 1.6%       |
| Near-field integration | $\eta_{\text{nf\_surface}}$ | 98.4%      |
| Quantum efficiency | $\eta_{\text{QE}}$ | 84.5%      |
| Spiral scattering | $\eta_{\text{sca}}$ | 65.2%      |
| SPP absorption   | $\eta_{\text{abs\_spp}}$ | 8.2%       |
| SPP residual     | $\eta_{\text{res}}$ | 5.7%       |
Fig. S9. Numerically simulated Stokes parameter $S_3$. Numerically simulated Stokes parameter $S_3$ for the configurations without any structure (A) and with spiral gratings of arm number $m = -1$ (B), $-3$ (C) and $-5$ (D), respectively.
Fig. S10. The intensity overlaps between RCP and LCP components.
Fig. S11. Fabrication process of the OAM sources.
Fig. S12. Deterministic positioning procedure of NDs containing multiple-NVs. (A) Dark-field image with four alignment Au markers. (B) The four markers are located to construct the frame of a 100 µm × 100 µm coordinate system. The centers of four markers, upper-left (UL), lower-left (LL), upper-right (UR) and lower-right (LR), are defined by the black dash crosshairs. (C) The zoomed-in window of the selected ND-NV. (D and E) Gaussian fitting of the selected ND-NV in (C) along the x- and y-axis to calculate its coordinates.
Fig. S13. Profiles of the fabricated HSQ spiral grating. (A) 3D AFM profiles of the fabricated one-armed HSQ spiral grating. (B) Height distributions by line cut profile in (A). The middle lower peak denotes the height of the deterministically placed ND-NVs.
Fig. S14. Schematic of the optical setup for the far-field pattern (gray region), spectrum, and correlation (blue region) measurements. HWP: half-wave plate, M: refection mirror, PBS: polarizing beam splitter, RPC: radially polarizer converter, DM: dichroic mirror, QWP: quarter-wave plate, LP: linear polarizer, FM: flipped mirror, BFP: back focal plane, CMOS: digital camera, BS: 50: 50 beam splitter, APD: single photon avalanche photon diode, GM: galvanometric mirror.
Fig. S15. Measured total far-field patterns of fabricated OAM sources. Measured total far-field patterns of the fabricated OAM sources composed of NDs containing multiple-NVs and HSQ spiral gratings with arm numbers $m = -1$ (A), $-3$ (B), and $-5$ (C), respectively. There are no spectrum filters used.
Fig. S16. Experimental implementation of the OAM single-photon source. (A–C) Measured total (A), RCP (B), and LCP (C) far-field patterns of the OAM single-photon source in Fourier plane. (D and E) Fluorescence images before (D) and after (E) fabricating the one-armed HSQ spiral grating around the selected ND containing single NV. (F and G) Measured correlation before (F) and after (G) fabricating the HSQ spiral grating.
Fig. S17. Measured spectrum, lifetime, and stability of the single-NV ND. (A and B) Measured spectrum (A) and lifetime (B) of the single-NV ND before and after fabricating the one-armed HSQ spiral grating. (C) Count trace for stability test without any operation, 10ms/bin.
Fig. S18. Modified Michelson interferometer (gray region) for fluorescence interference. Flipping DM to BS to allow reference light aligning.
Fig. S19. Displacement-dependence of interference patterns. (A) Displacement-dependence of interference patterns in total fields. (B and C) Interference patterns of RCP (B) and LCP (C) components with two different displacements. The emission is from the one-armed multiphoton OAM source.
Fig. S20. Schematic of the optical setup for OAM mode purity measurement and quantum state tomography (gray region). The HWP is removed for OAM mode purity measurement.
Fig. S21. Measured mode purity. (A and D) Mode purity of RCP (A) and LCP (D) components. (B and E) Selected phase profiles with different topological charges on the SLM for RCP (B) and LCP (E) components. (C and F) Far-field patterns in Fourier plane after reflecting from SLM with selected phases for RCP (C) and LCP (F) components.
Fig. S22. Simulated mode purity. Simulated mode purity of RCP (A) and LCP (B) components at the emission wavelength of 670 nm.
Table S3. A set of 16 tomographic projection measurements for SAM and OAM basis. The right panel lists the phase profiles ranging from 0, 0 to 2π and 0 to π on SLM, respectively.

|   | Polarization projection | OAM projection |
|---|-------------------------|----------------|
|   | QWP | HWP | LP | SLM |
| 1 | \(|R\rangle\) | 45° | 0° | 90° | \(|l = 0\rangle\) |
| 2 | \(|R\rangle\) | 45° | 0° | 90° | \(|l = 2\rangle\) |
| 3 | \(|R\rangle\) | 45° | 0° | 90° | \(|l = +\rangle\) |
| 4 | \(|R\rangle\) | 45° | 0° | 90° | \(|l = +i\rangle\) |
| 5 | \(|L\rangle\) | -45° | 0° | 90° | \(|l = 0\rangle\) |
| 6 | \(|L\rangle\) | -45° | 0° | 90° | \(|l = 2\rangle\) |
| 7 | \(|L\rangle\) | -45° | 0° | 90° | \(|l = +\rangle\) |
| 8 | \(|L\rangle\) | -45° | 0° | 90° | \(|l = +i\rangle\) |
| 9 | \(|H\rangle\) | 0° | 45° | 90° | \(|l = 0\rangle\) |
| 10 | \(|H\rangle\) | 0° | 45° | 90° | \(|l = 2\rangle\) |
| 11 | \(|H\rangle\) | 0° | 45° | 90° | \(|l = +\rangle\) |
| 12 | \(|H\rangle\) | 0° | 45° | 90° | \(|l = +i\rangle\) |
| 13 | \(|D\rangle\) | 45° | 22.5° | 90° | \(|l = 0\rangle\) |
| 14 | \(|D\rangle\) | 45° | 22.5° | 90° | \(|l = 2\rangle\) |
| 15 | \(|D\rangle\) | 45° | 22.5° | 90° | \(|l = +\rangle\) |
| 16 | \(|D\rangle\) | 45° | 22.5° | 90° | \(|l = +i\rangle\) |
Fig. S23. Impact of the ND-NV location on the performance. Simulated far-field intensity distributions (B), collection efficiencies (C), and mode purities (D) of RCP and LCP components at the emission wavelength of 670 nm when the z-oriented dipole is displaced from the center. To calculate the mode purity, the maximum intensity of each RCP Gaussian beam has been located and used as the center for OAM projection.
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