Composite picosecond control of atomic state through a nanofiber interface

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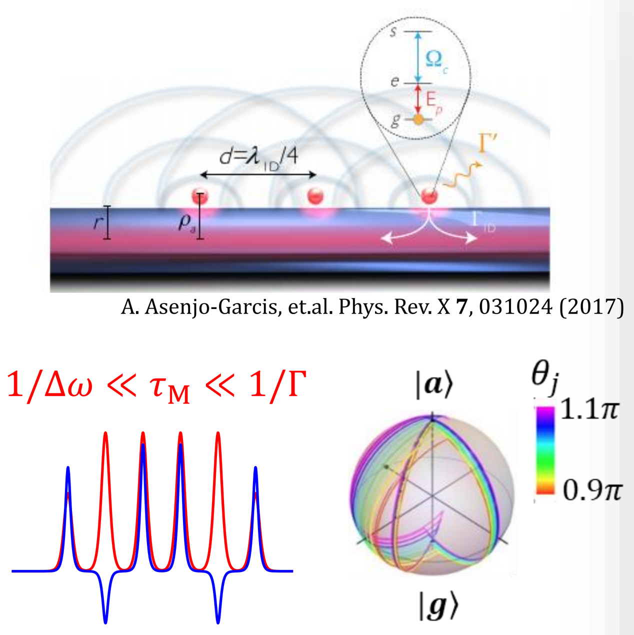
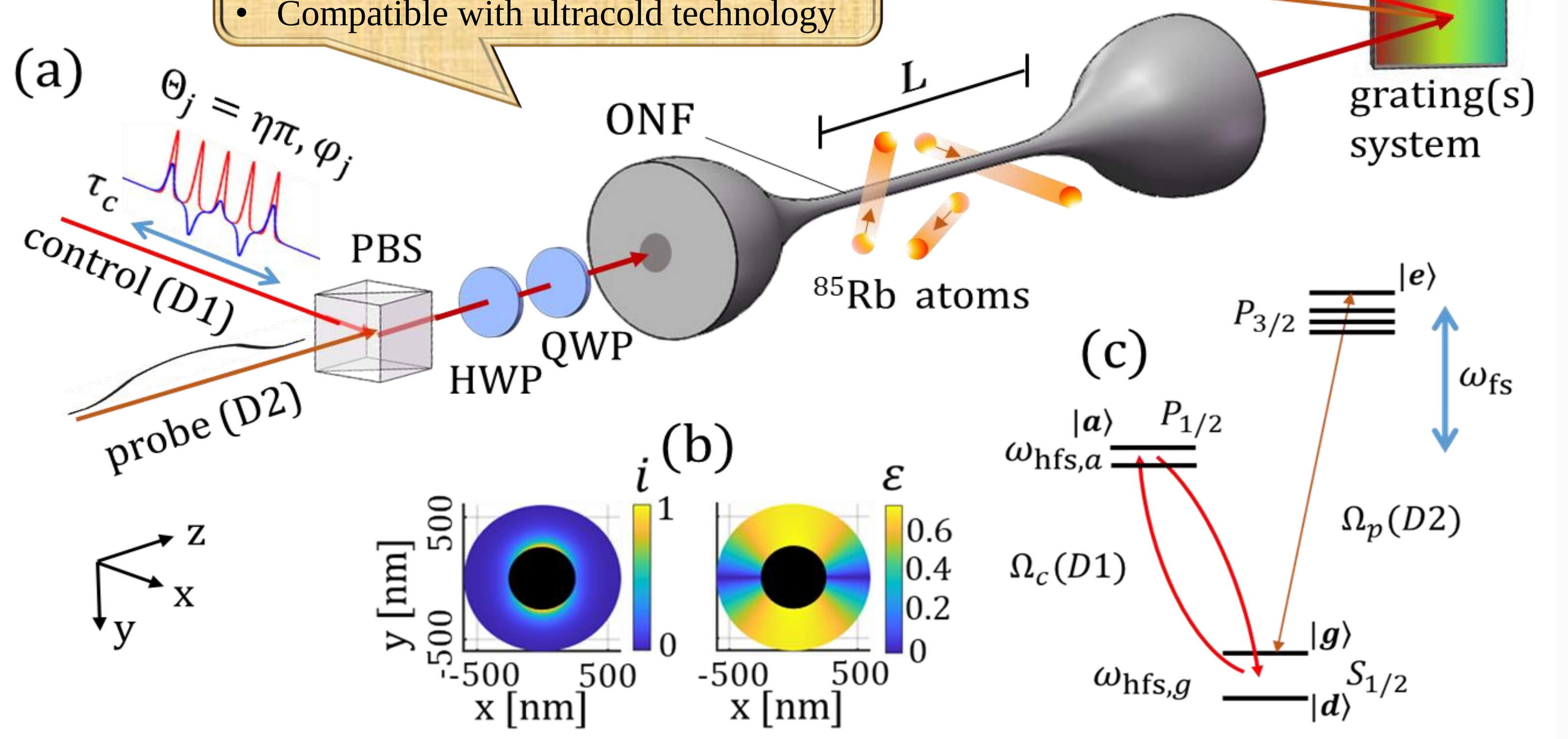
Introduction

- Nanophotonic interfaces: strong interaction between confined photons and nearby atoms.
- We propose to achieve high precision nanophotonic control of atomic states by composite control schemes with arrays of picosecond pulses.
- This work: A proof-of-concept by controlling a strong transition of room-temperature atoms at a nanofiber interface.



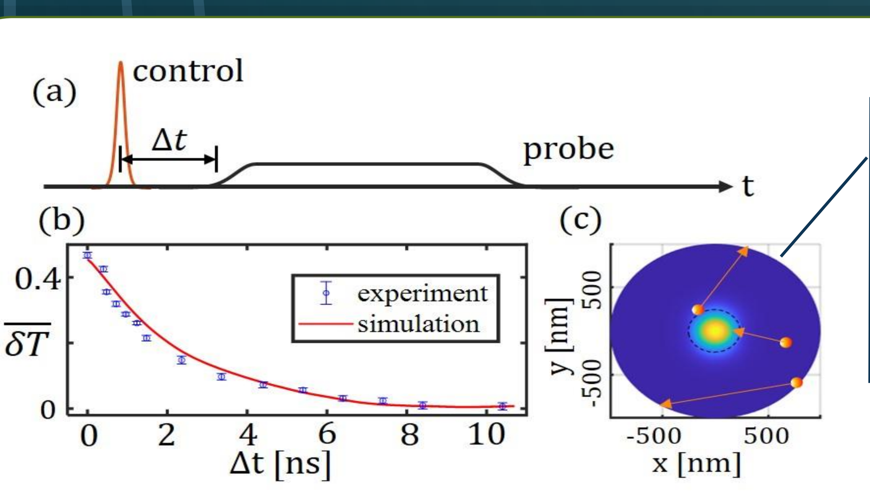
Experimental Setup

- Optical confinement over long distance
- Evanescent strong coupling
- Compatible with ultracold technology



- State-of-art atom-nanofiber interface. (L.Tong, Opt. Express,**12**, 1025(2004), D.Su, New J. Phys. **21**, 043053(2019)).
- Novel picosecond pulse shaping scheme for strong transition control [1].
- Composite picosecond D1 pulses to control transmission at D2.
- Controlling atoms at 300 m/s across the sub-micron evanescent field.
- Polarized control by ellipticity distribution ε(r).

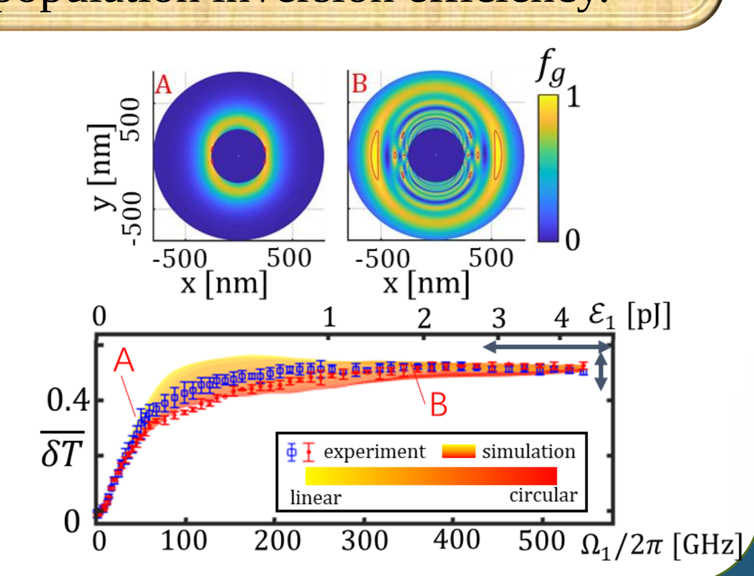
One pulse benchmark



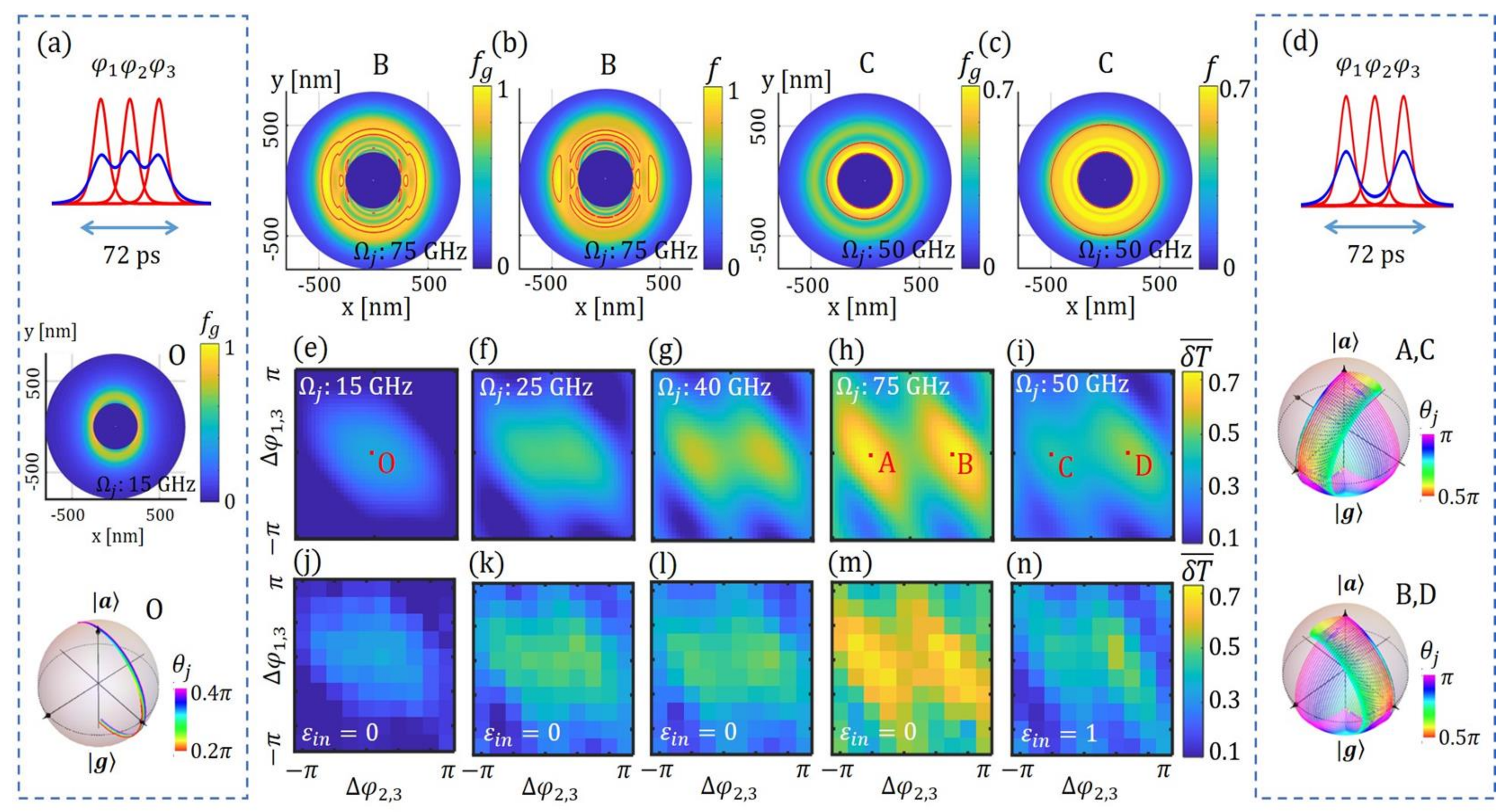
- We use a Monte Carlo simulation to recover the optical response of the moving atoms (red curve in Fig.(b)).

- For N=1 picosecond control pulse, we delay the probe Δt to study the transient optical response of the thermal atoms (Fig. (a)). The result is shown in Fig. (b) with scatter plots. Here $\overline{\delta T}$ represents the control induced relative probe transmission, which reflects the D1 population inversion efficiency.

- We scan the control pulse energy $\mathcal{E}_1$ with linear or circular incident polarization at Δt=0.
- A optical saturation of $\overline{\delta T}$, which is up to ~45%.
- Polarization-dependent response.

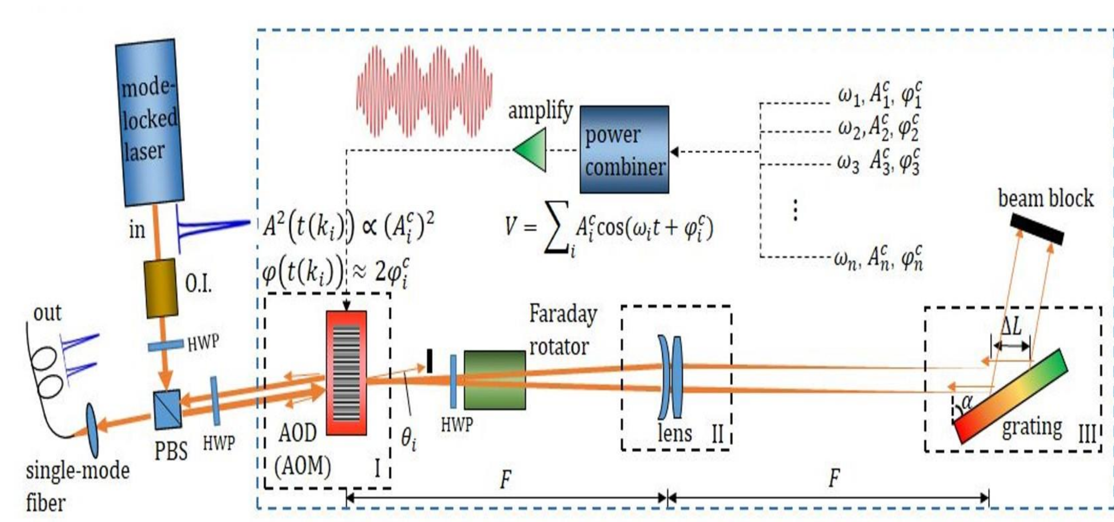


Composite control with a three-pulse seq.



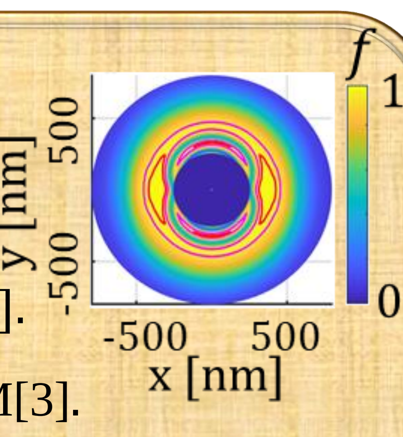
- We apply a phase-coherent N=3 pulse sequence to control the atoms in the evanescent field. Figs. (j-n) show the experimental measured $\overline{\delta T}$ at different incident polarization and power (associated Ω_j).
- The experimental observations are corroborated with a full-level simulation (Figs. (e-i)).
- The broken sign symmetry in Fig.(i)(n) is associated with substantial $|g\rangle \leftrightarrow |d\rangle$ Raman transfer, as unveiled by comparing ρ_{gg}- depletion efficiency f_g(r) with expected inversion efficiency f(r) in Fig. (c) according to the full-level simulations.
- Behind the ~70% enhancement to the probe transmission is local population inversion efficiency of >90% (red curve in Fig.(b)) over a 100nm-sized area, well suitable for controlling confined atoms in future work.

Pico-second pulse shaping technique



- An overview of the pulse shaping technology for the robust strong transition control.
- Phase stable, fully programmable

- Toward larger N
  - Expected inversion efficiency f(r) for N=5 picosecond control pulse sequence (red curve >99%).
  - Technical issues: AOM nonlinearity and cross-talk[1].
  - An upgraded pulse shaping system by composite AOM[3].
  - High resolution monitor system for the pulse sequence based on wavelength meter etalon signal .



Summary and outlook

- We demonstrate a composite picosecond pulse scheme to achieve error-resilient control of a strong transition within the proximity of an optical nanofiber. A phase-coherent 3-pulse sequence of excitation from a picosecond pulse shaper is found able to efficiently invert the D1 transition of a ^{85}Rb vapor across the evanescent field, leading to an enhancement of fiber transmission of a nanosecond D2 probe by up to ~70%.
- Confirmed by a full-level simulation, this composite scheme supports highly efficient optical control of alkaline atoms near a nanofiber. By successively applying two inversions, a precise phase gate can be achieved to control the collective atom-fiber coupling. This research may open a door to new quantum optical research at ultra-low light level.

Acknowledgement & Reference

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