Optical Levitation of Nanodiamonds by Doughnut Beams in Vacuum

Wada Shotaro

2017/10/13

Ando Lab Seminar

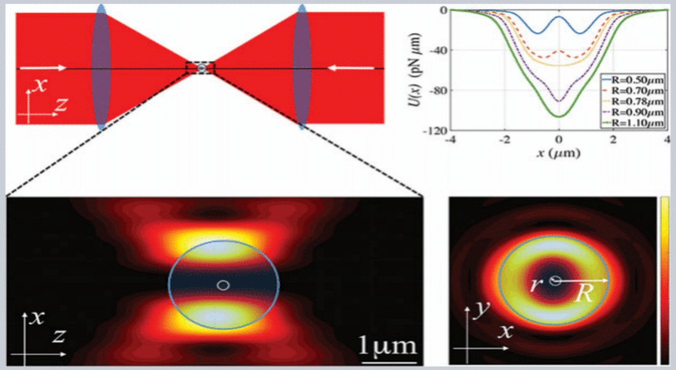
Paper

“Optical levitation of nanodiamonds by doughnut beams in vacuum” (L.M.Zhou et al.,2017)

LASER & PHOTONICS REVIEWS

Laser Photonics Rev. **11**, No. 2, 1600284 (2017) / **DOI** 10.1002/lpor.201600284

Abstract Optically levitated nanodiamonds with nitrogen-vacancy centers promise a high-quality hybrid spin-optomechanical system. However, the trapped nanodiamond absorbs energy from laser beams and causes thermal damage in vacuum. It is proposed here to solve the problem by trapping a composite particle (a nanodiamond core coated with a less absorptive silica shell) at the center of strongly focused doughnut-shaped laser beams. Systematical study on the trapping stability, heat absorption, and oscillation frequency concludes that the azimuthally polarized Gaussian beam and the linearly polarized Laguerre-Gaussian beam LG_{03} are the optimal choices. With our proposal, particles with strong absorption coefficients can be trapped without obvious heating and, thus, the spin-optomechanical system based on levitated nanodiamonds are made possible in high vacuum with the present experimental techniques.



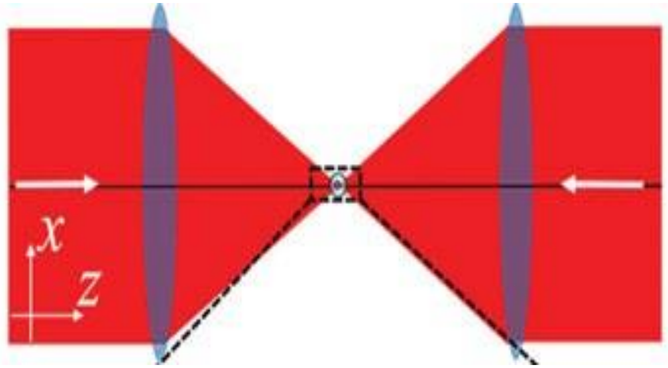
ORIGINAL PAPER

Optical levitation of nanodiamonds by doughnut beams in vacuum

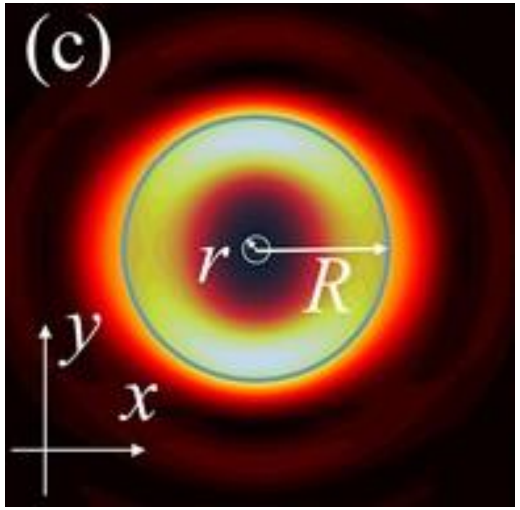
Lei-Ming Zhou[1], Ke-Wen Xiao[1], Jun Chen[2], and Nan Zhao[1,*]

Abstract

・Optical levitated nanodiamonds are spin-optomechanical system



・The trouble is that beams heat diamond

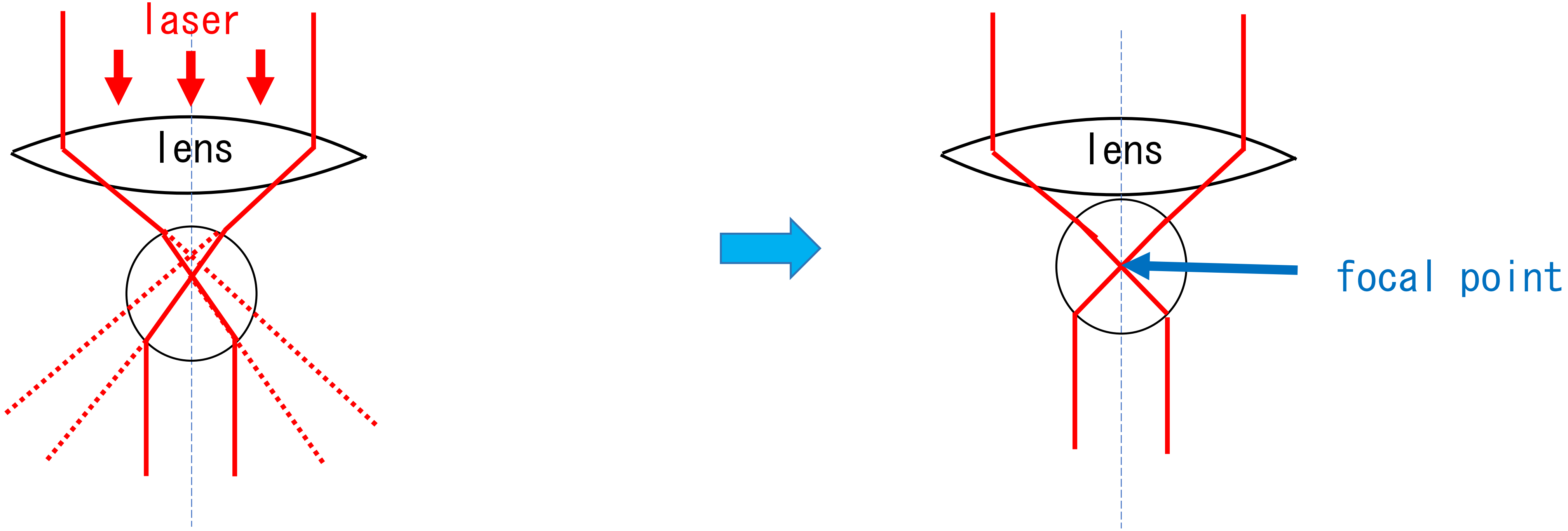


・They propose to use doughnut-shaped laser beams

Contents

1. Introduction

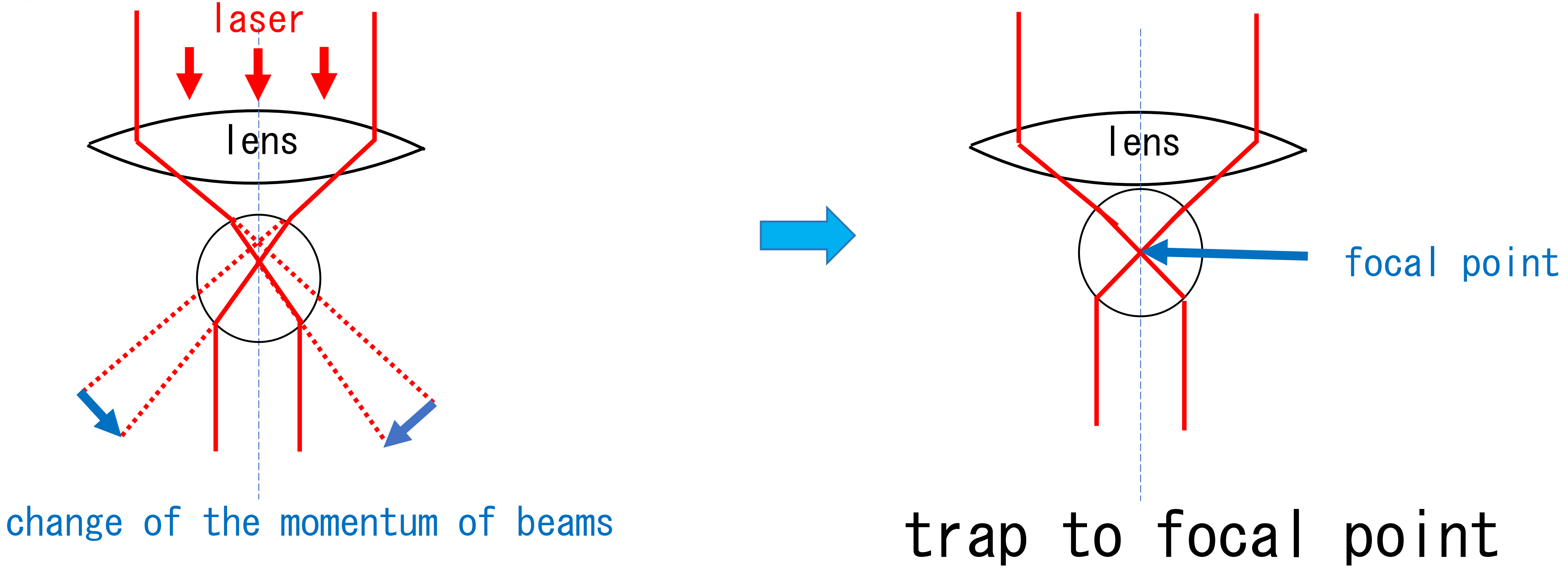
Optical tweezers



trap to focal point

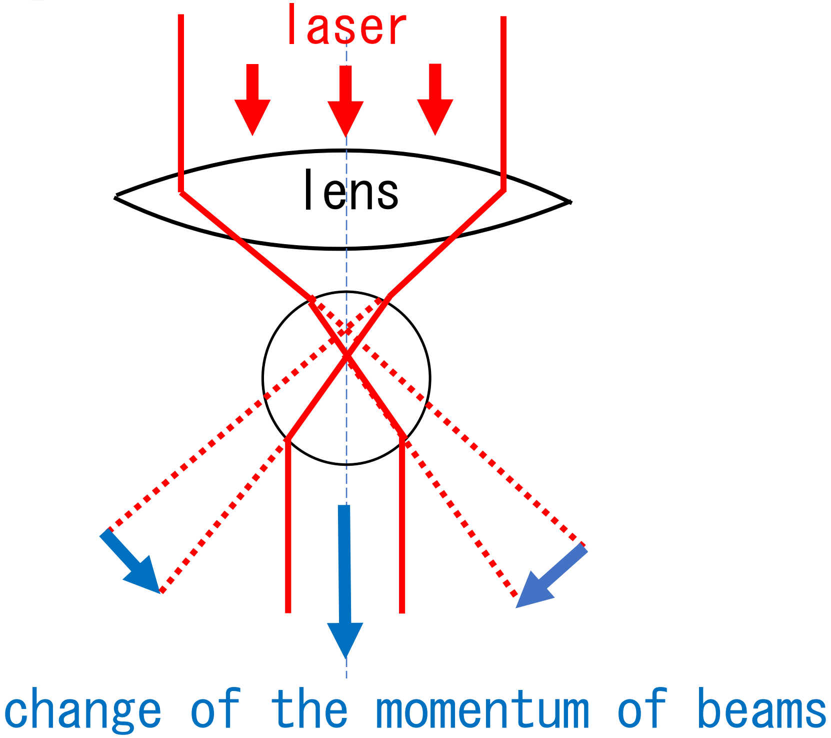
Optical tweezers are widely used

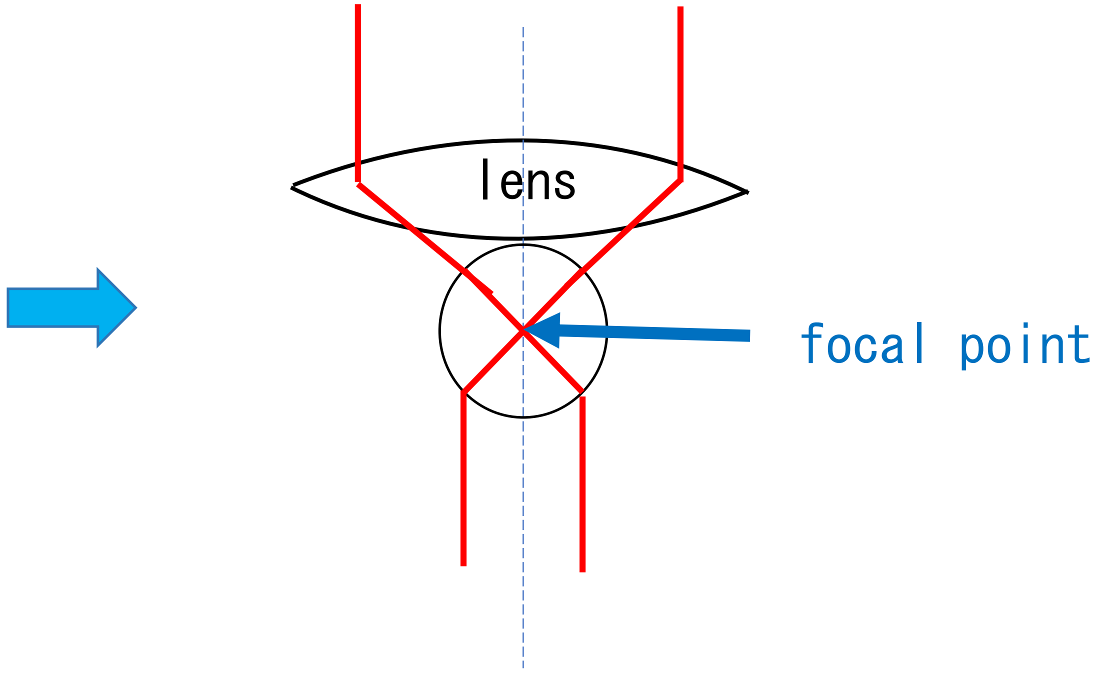
Optical tweezers



Optical tweezers are widely used

Optical tweezers

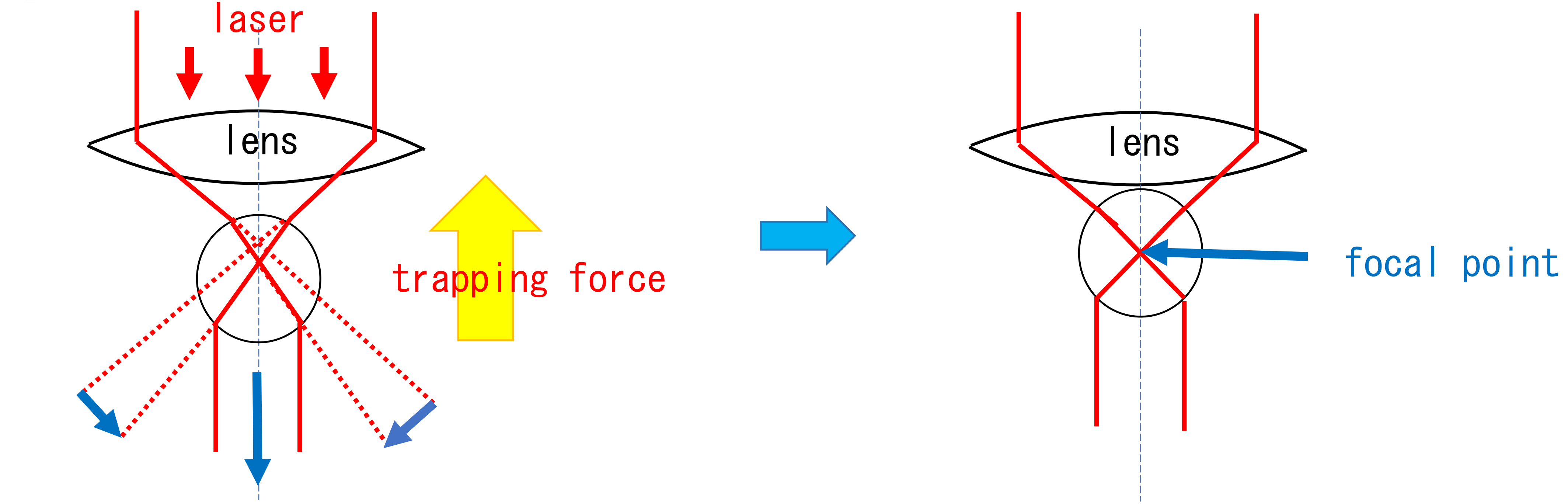




trap to focal point

Optical tweezers are widely used

Optical tweezers



trap to focal point

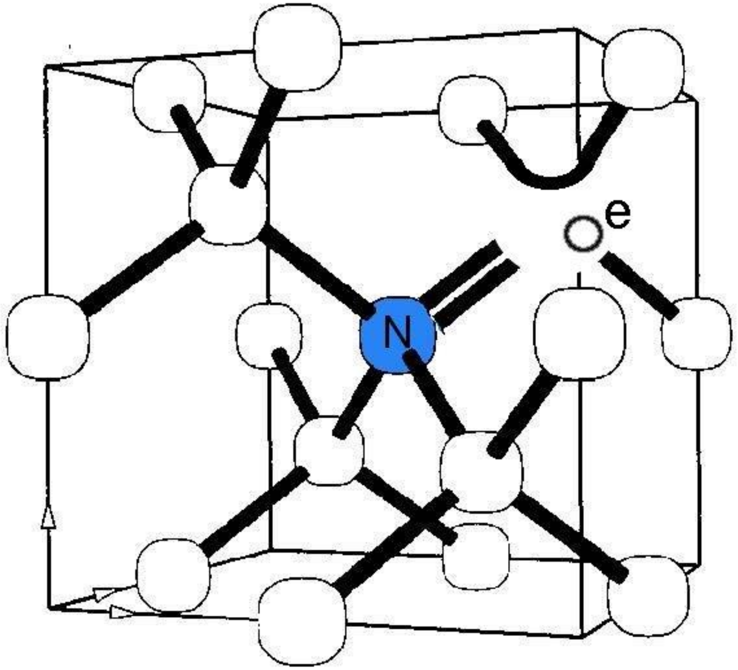
Optical tweezers are widely used

Optical levitation of nanodiamonds

Nanodiamond nitrogen-vacancy (NV) centers are used quantum elements

Merit

- long spin coherence time($\sim 10^2 \mu s$)
- high quality factor ($\sim 10^{10}$ in $\mathrm{P} = 10^{-6} Pa$)



Nanodiamond NV centers

Problems

Thermal damage problem

Diamonds absorb energy from laser

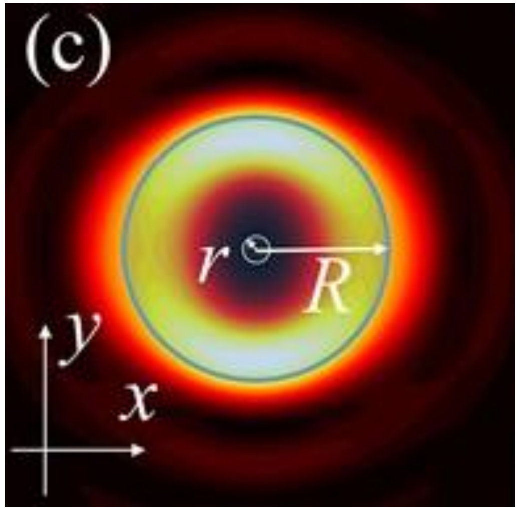
① reduce the heat absorption
② improve the laser

2. Proposal

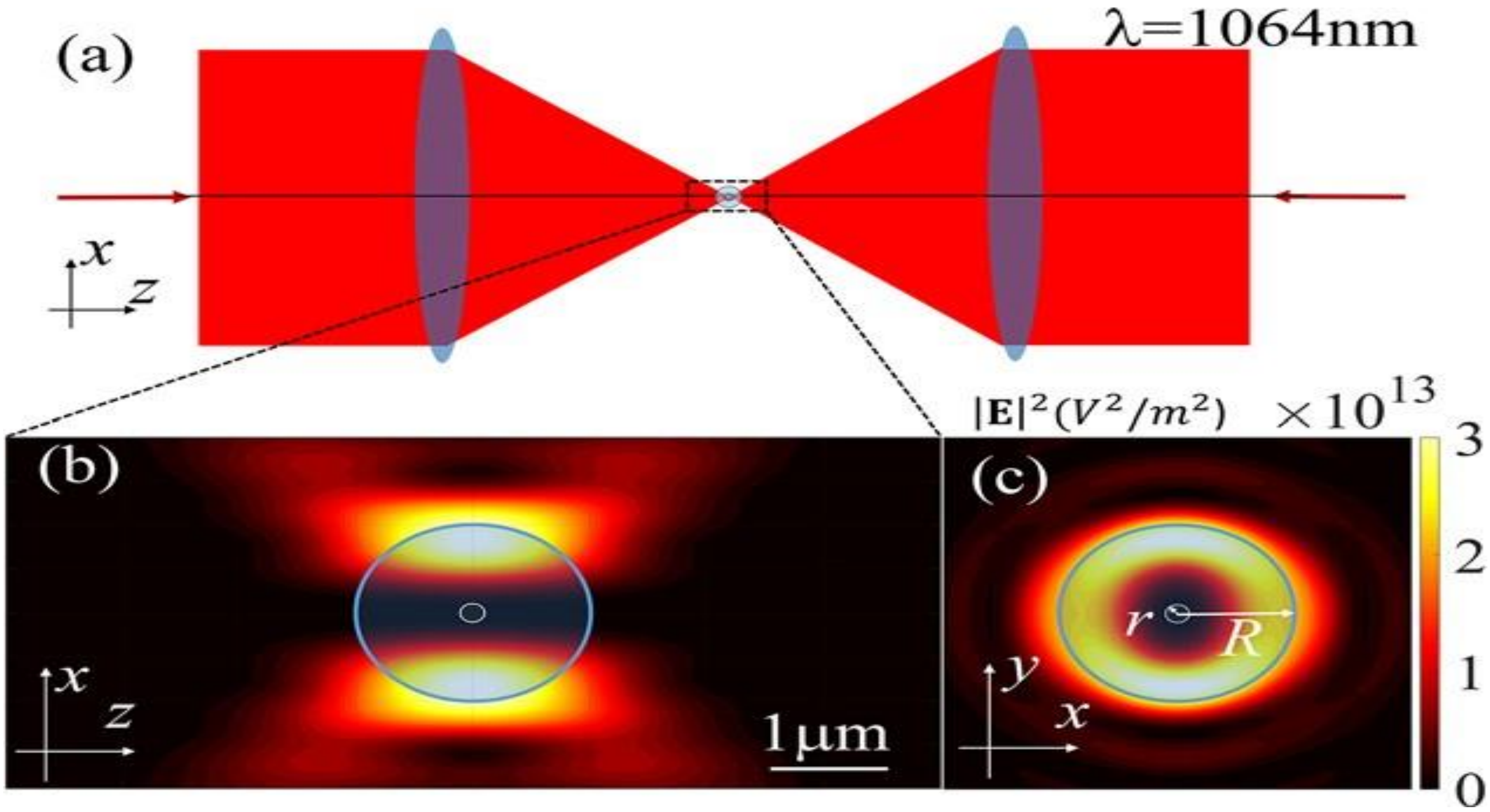
Proposal

① reduce the heat absorption
→ silica coat nanodiamonds

② improve the laser
→ doughnut laser



Setup of the system



core radius
r=100 nm

shell radius
R=1 μm

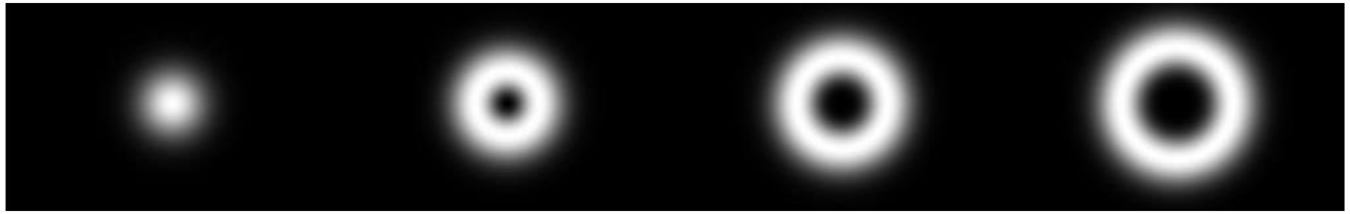
P=100 mW

(a)The setup of the system
(b)Front view and (c)side view of the beam

A kind of doughnut beams

Laguerre-Gaussian (LG) beam $LG_{0l}(l = 0,1,2,\cdots)$

LG_{0l}



$l = 0$ $l = 1$ $l = 2$ $l = 3$

(OAM)

l:orbital angular moment

Polarization

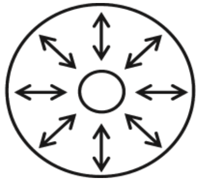
circularly polarization

linearly polarization

linearly polarization

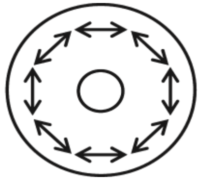
Each LG_{0l} beams has two types

cylindrical vector beams



(a)

radial polarized



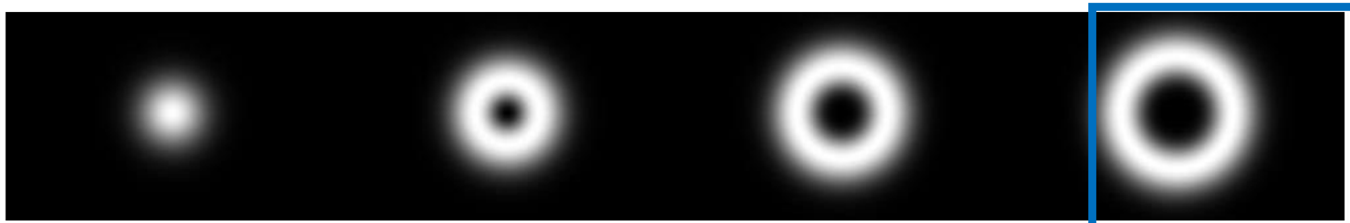
(b)

azimuthally polarized

A kind of doughnut beams

Laguerre-Gaussian (LG) beam $LG_{0l}(l = 0,1,2,\cdots)$

LG_{0l}



$l = 0$ $l = 1$ $l = 2$ $l = 3$

l:orbital angular moment (OAM)

Polarization

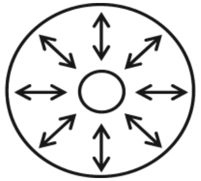
circularly polarization

linearly polarization

linearly polarization

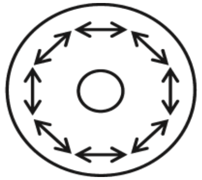
Each LG_{0l} beams has two types

cylindrical vector beams



(a)

radial polarized



(b)

azimuthally polarized

Good!

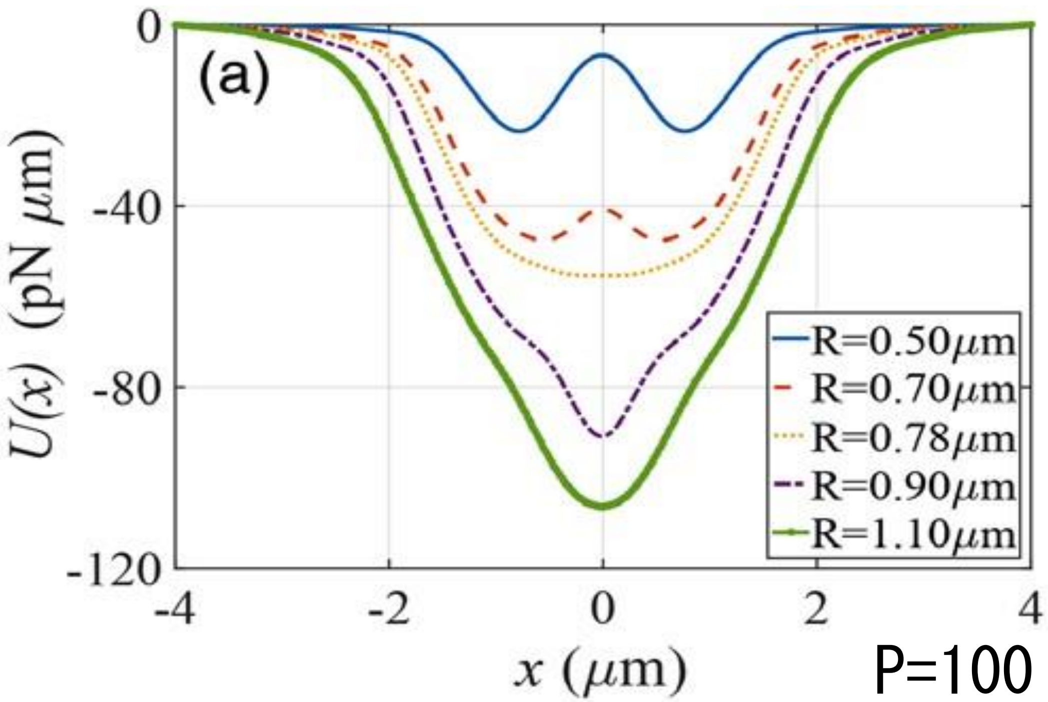
3. Trapping stability

Optical trapping potential

Particle size must exceed a critical radius R_{trans}

・$\mathrm{R} < R_{trans}$
$U(x)$ has a double-well

・$\mathrm{R} > R_{trans}$
$U(x)$ has a single-well



P=100 mW

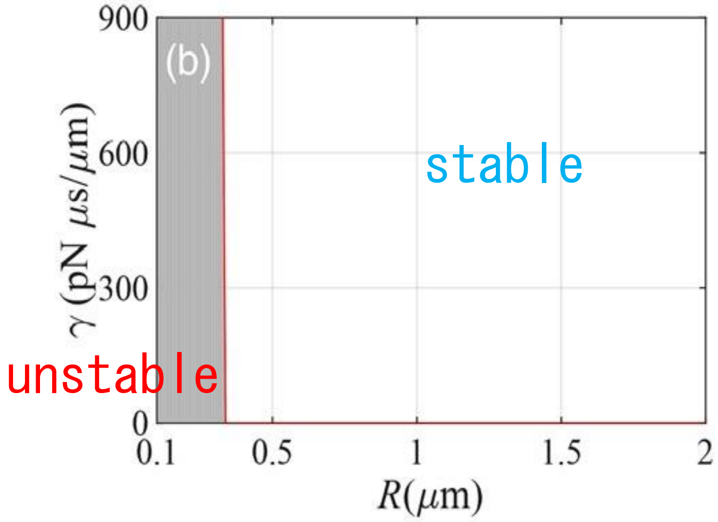
linearly potential LG_{03} beam

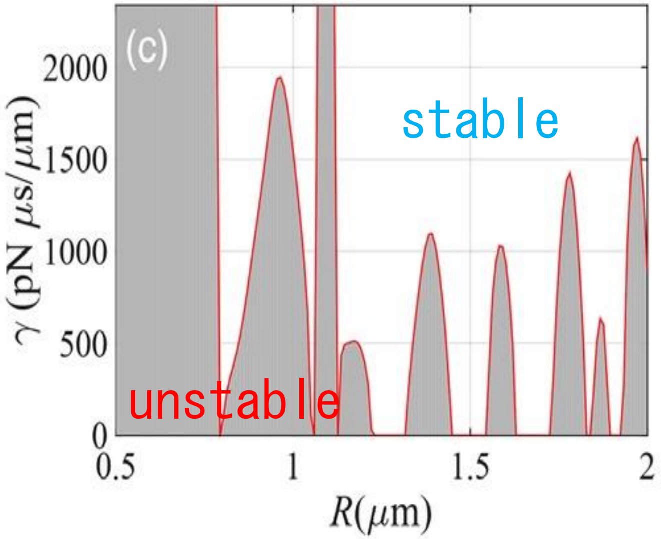
Stability in doughnut beams

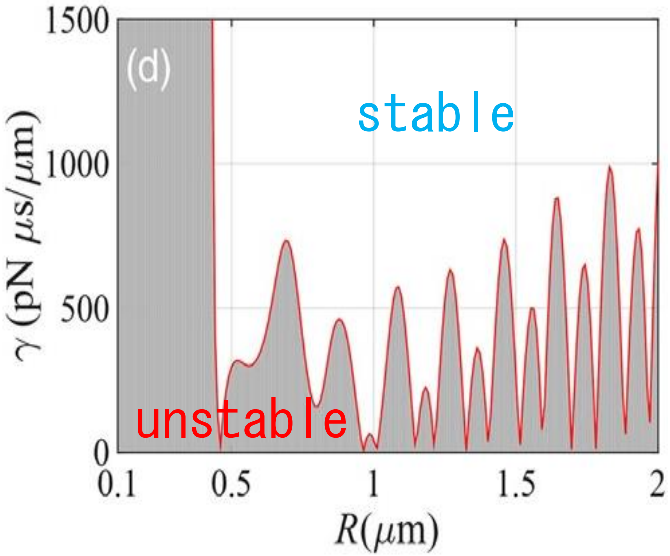
Stability depends on polarization

γ: damping rate

$P = 100\ mW, r = 20\ nm$





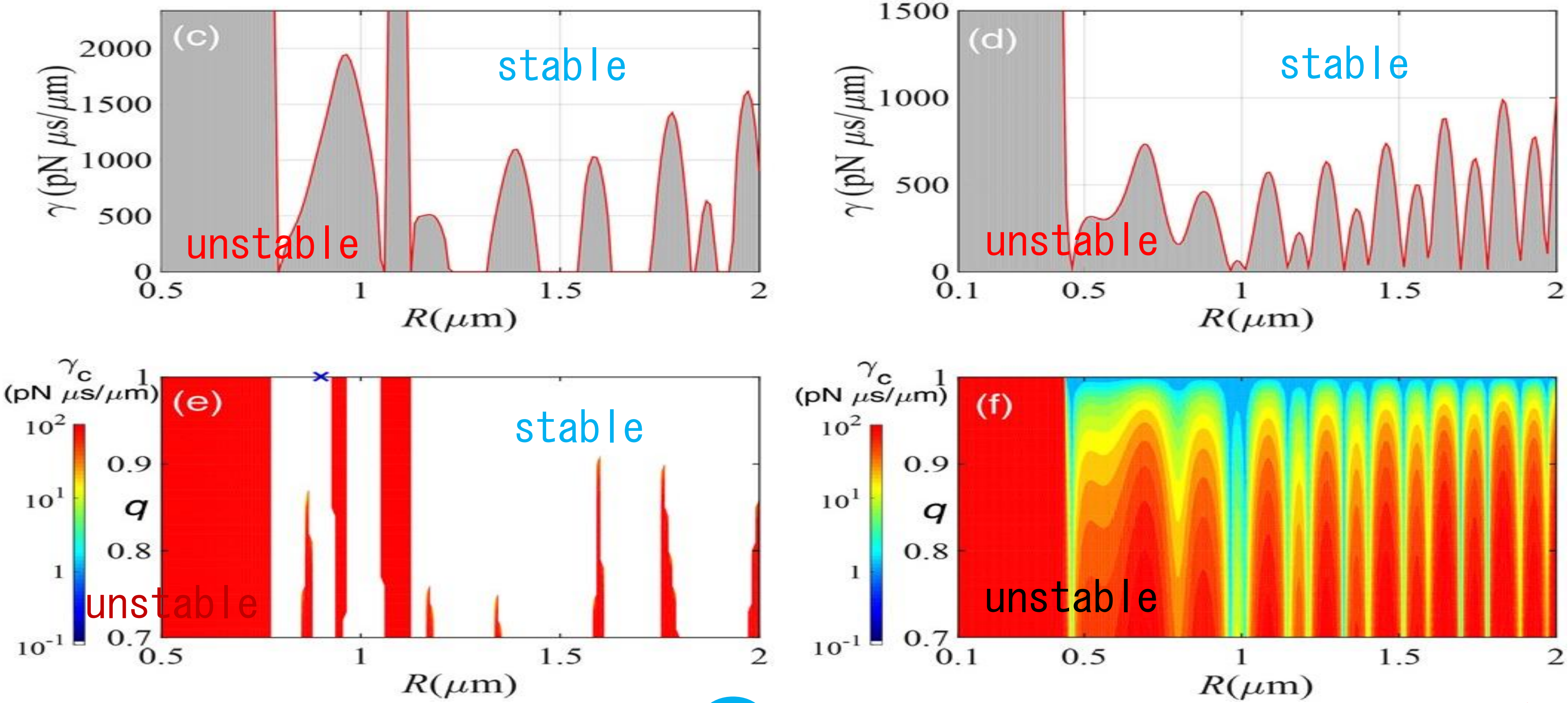


Azimuthally polarized beam ○

linearly polarized (LG_{03}) ○

circularly polarized (LG_{01}) ×

Stability in doughnut beams



$P = 100\ mW$
$r = 20\ nm$

$P_2 = qP_1$

linearly polarized (LG_{03}) ○

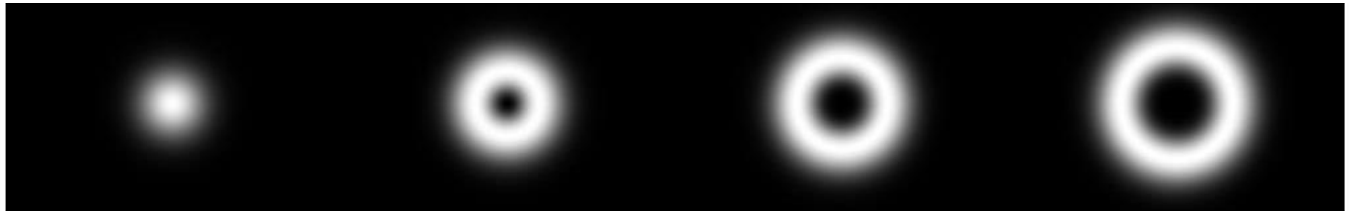
circularly polarized (LG_{01}) ✕

Circularly polarized LG are NOT appropriate

A kind of doughnut beams

Laguerre-Gaussian (LG) beam $LG_{0l}(l = 0,1,2,\cdots)$

LG_{0l}



$l = 0$ $l = 1$ $l = 2$ $l = 3$

l:orbital angular moment (OAM)

Polarization

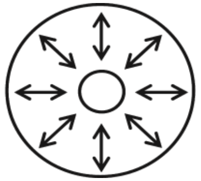
circularly polarization

linearly polarization

linearly polarization

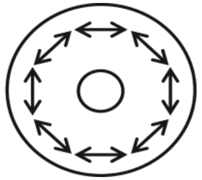
Each LG_{0l} beams has two types

cylindrical vector beams



(a)

radial polarized



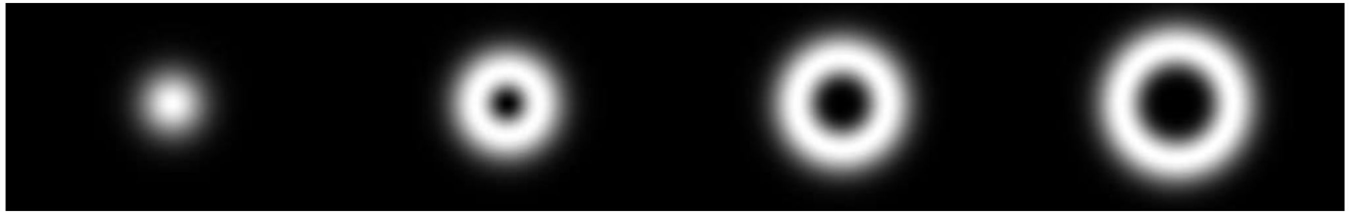
(b)

azimuthally polarized

A kind of doughnut beams

Laguerre-Gaussian (LG) beam $LG_{0l}(l = 0,1,2,\cdots)$

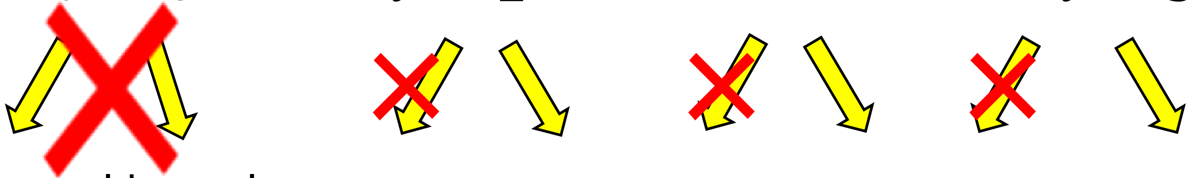
LG_{0l}



(OAM)

$l = 0$ $l = 1$ $l = 2$ $l = 3$ l:orbital angular moment

Polarization



circularly polarization linearly polarization

linearly polarization

Each LG_{0l} beams has two types

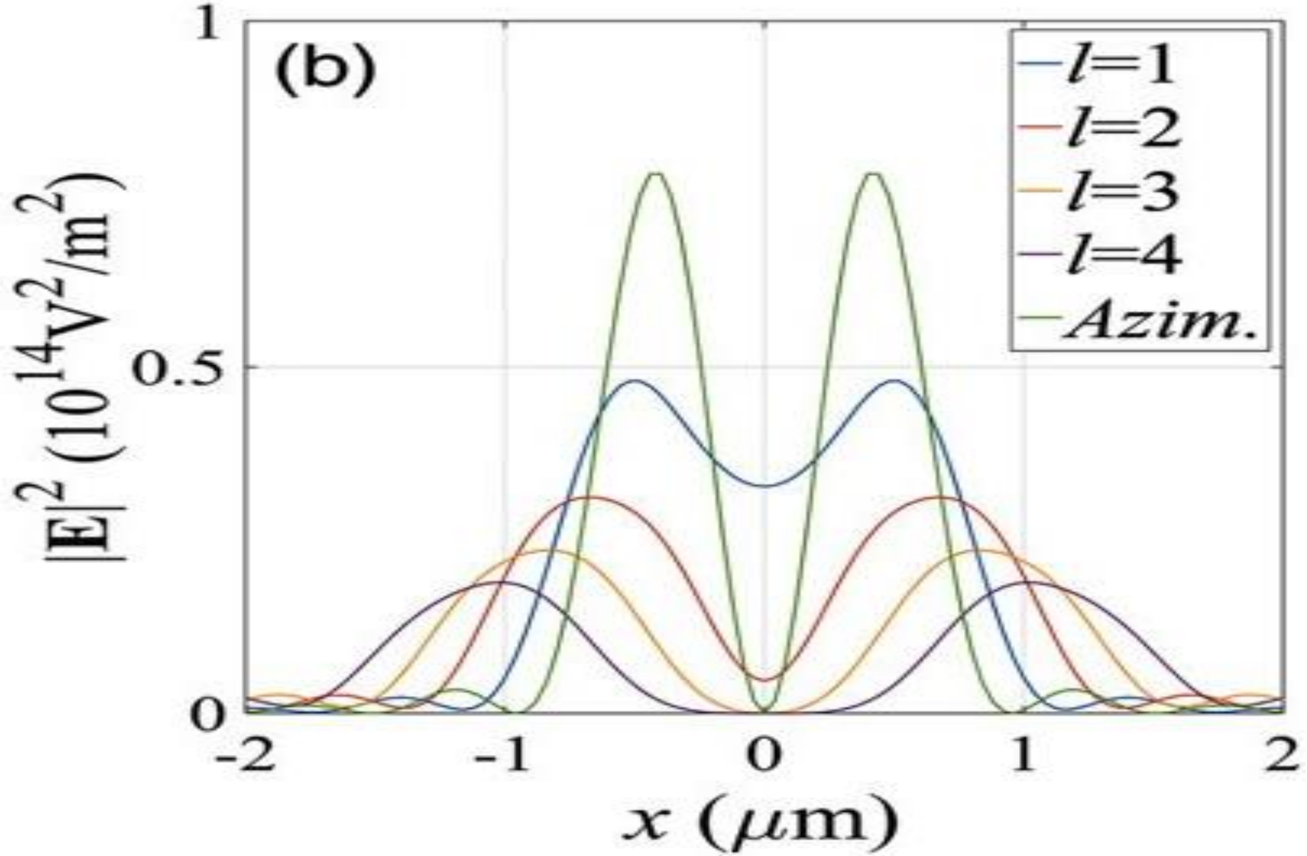
cylindrical vector beams

radial polarized azimuthally polarized

4. Suppression of heat absorption

Intensity distribution

The heat absorption depends on both polarization and OAM



Intensity of beam

azimuthal polarized

$$I_a = A_a(kx)^2$$

LG_{ol} beam

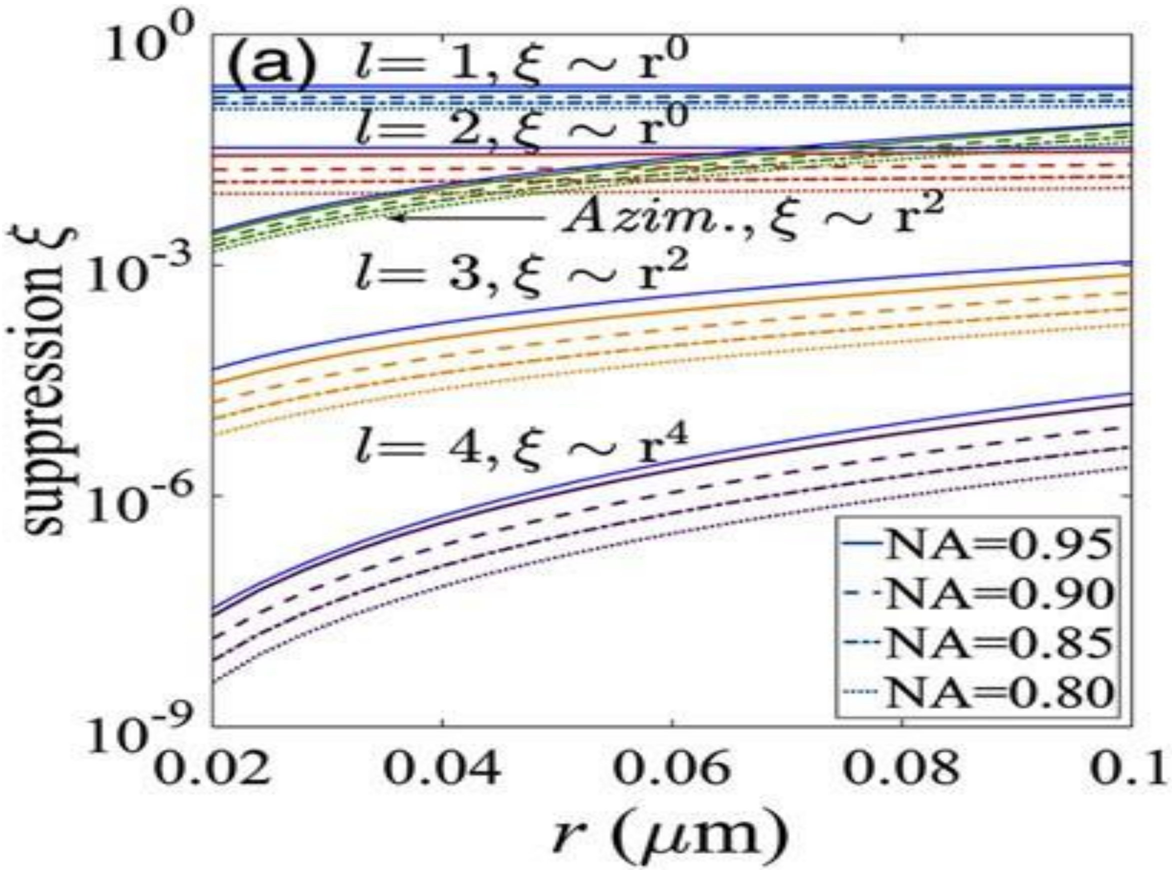
$$I_{1,2} = A_{1,2} \neq 0 \quad (l = 1,2)$$

$$I_3 = A_3(kx)^2 \quad (l = 3)$$

$$I_4 = A_4(kx)^4 \quad (l = 4)$$

Suppression of heat absorption

The heat absorption depends on both polarization and OAM



suppression ratio

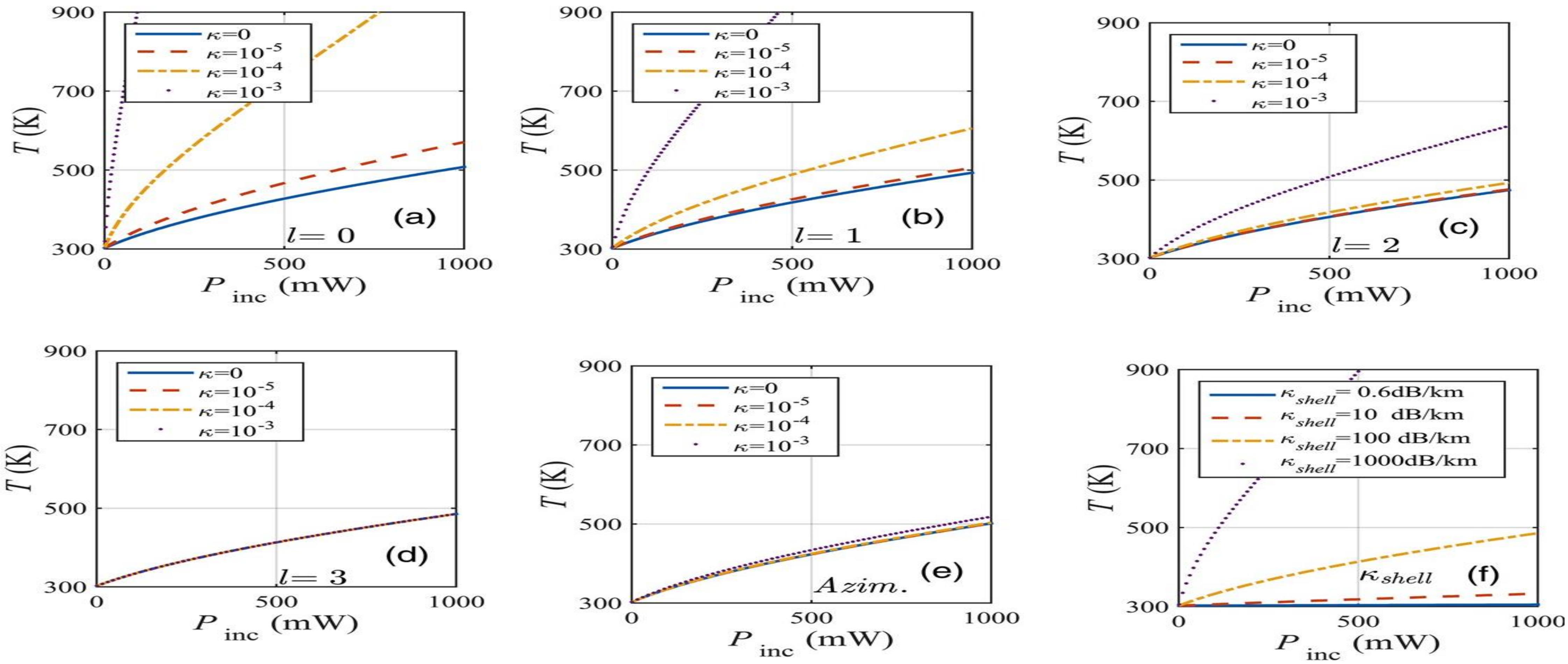
$$\xi \equiv \frac{c_{abs}}{c_{abs,0}}$$

c_{abs}:absorptive coefficient
$c_{abs,0}$:absorptive coefficient in Gaussian beam

R=900 nm, $P_1 = P_2 = 50\,mW$

$LG_{01,02}$ are NOT appropriate

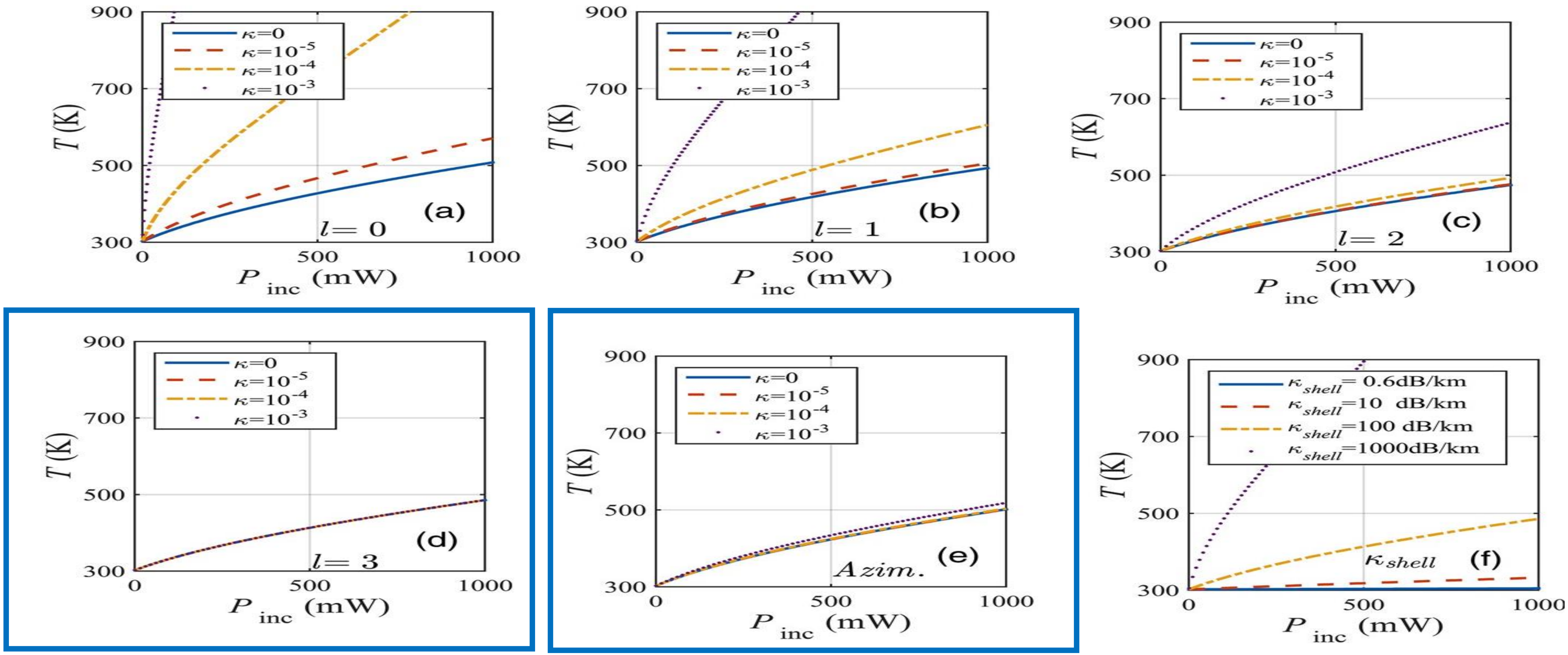
The equilibrium temperature



κ:imaginary part of refractive index of core

κ_{shell}:shell absorptive coefficient

The equilibrium temperature



Good!

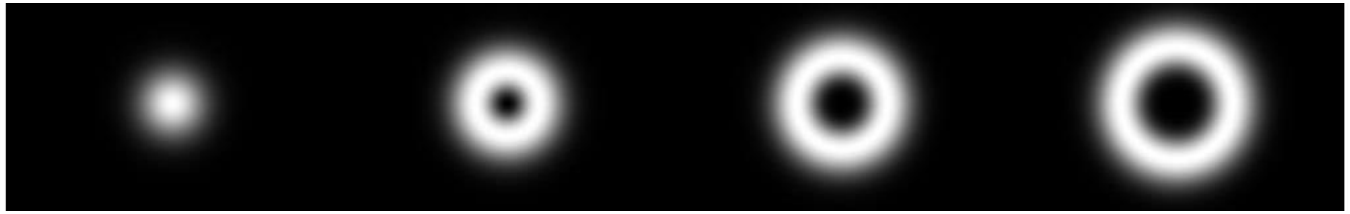
κ:imaginary part of refractive index of core

κ_{shell}:shell absorptive coefficient

A kind of doughnut beams

Laguerre-Gaussian (LG) beam $LG_{0l}(l = 0,1,2,\cdots)$

LG_{0l}

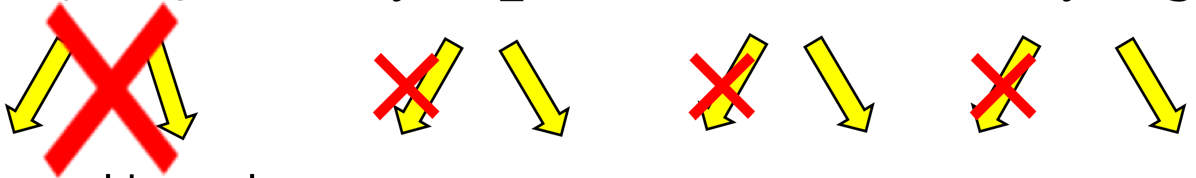


$l = 0$ $l = 1$ $l = 2$ $l = 3$

(OAM)

l:orbital angular moment

Polarization



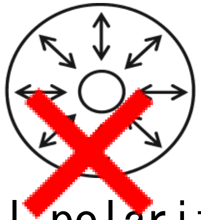
circularly polarization

linearly polarization

linearly polarization

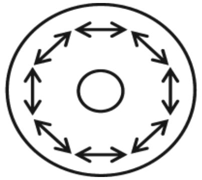
Each LG_{0l} beams has two types

cylindrical vector beams



(a)

radial polarized



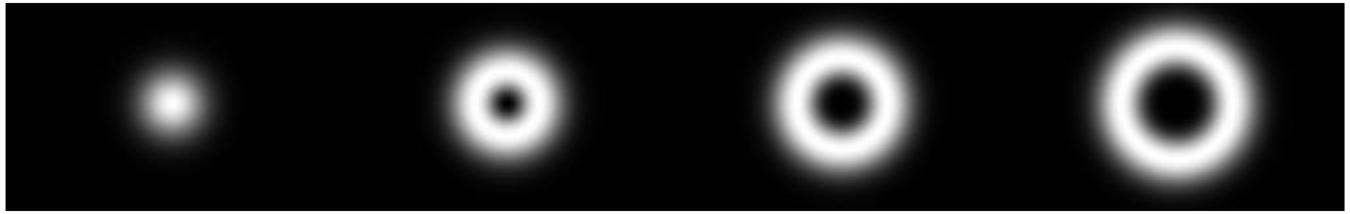
(b)

azimuthally polarized

A kind of doughnut beams

Laguerre-Gaussian (LG) beam $LG_{0l}(l = 0,1,2,\cdots)$

LG_{0l}

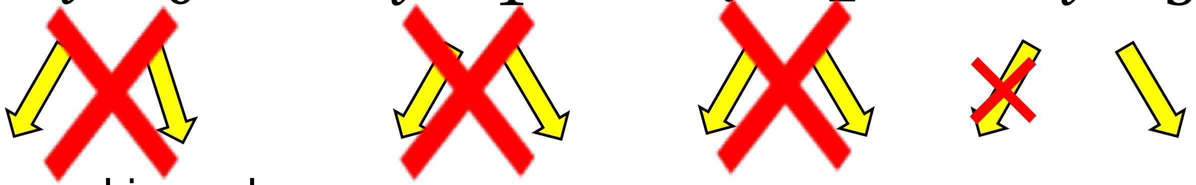


$l = 0$ $l = 1$ $l = 2$ $l = 3$

(OAM)

l:orbital angular moment

Polarization



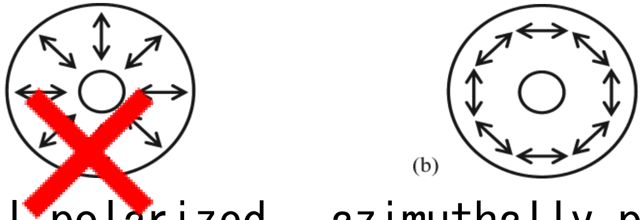
circularly polarization

linearly polarization

linearly polarization

Each LG_{0l} beams has two types

cylindrical vector beams



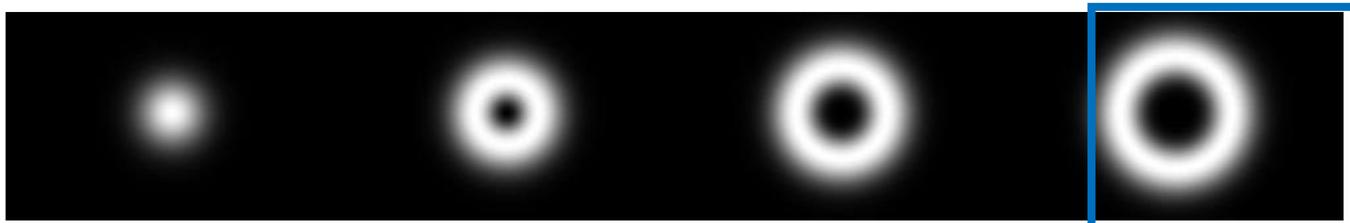
(a) radial polarized

(b) azimuthally polarized

A kind of doughnut beams

Laguerre-Gaussian (LG) beam $LG_{0l}(l = 0,1,2,\cdots)$

LG_{0l}



$l = 0$ $l = 1$ $l = 2$ $l = 3$

l: orbital angular moment (OAM)

Polarization

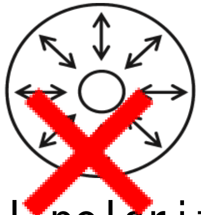
circularly polarization

linearly polarization

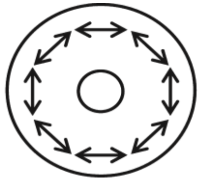
linearly polarization

Each LG_{0l} beams has two types

cylindrical vector beams



radial polarized

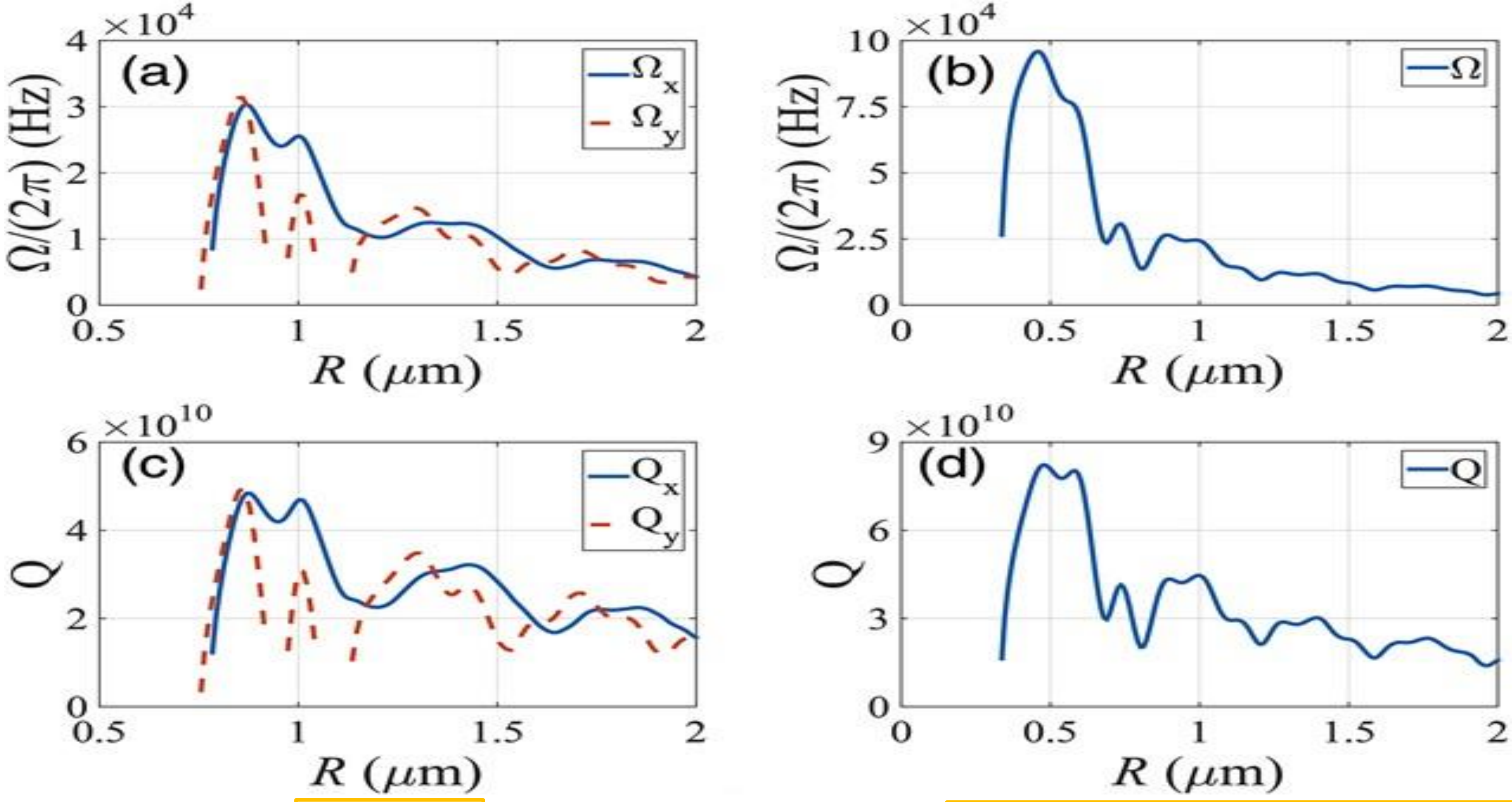


azimuthally polarized

Good!

5. Trapping frequency Ω and mechanical quality factor Q

Trapping frequency Ω and mechanical quality factor Q



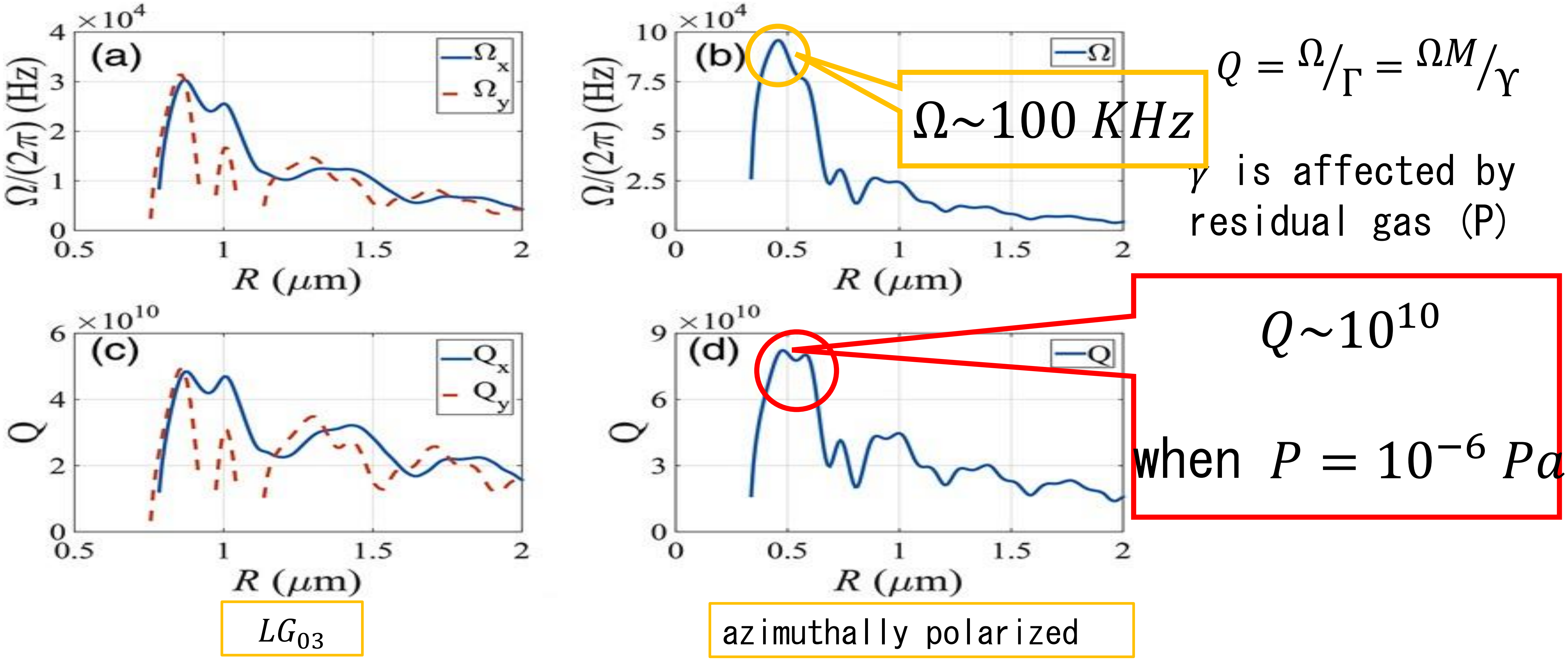
LG_{03}

azimuthally polarized

$$Q = {}^{\Omega}/_{\Gamma} = {}^{\Omega M}/_{\gamma}$$

γ is affected by residual gas (P)

Trapping frequency Ω and mechanical quality factor Q



$Q = \Omega/_{\Gamma} = \Omega M/_{\gamma}$

γ is affected by residual gas (P)

6. Conclusion

Conclusion

・They propose to use doughnut beams and core-shell particles

・Linearly polarized LG_{03} beams and azimuthally polarized beam are appropriated

・The low-absorptive shell (e.g., the silica shell) is useful

今日は本当に
申し訳ありませんでした