Analysis of the Optical Near-Field due to PbTe Thin Films for Super-resolution Optical Memory

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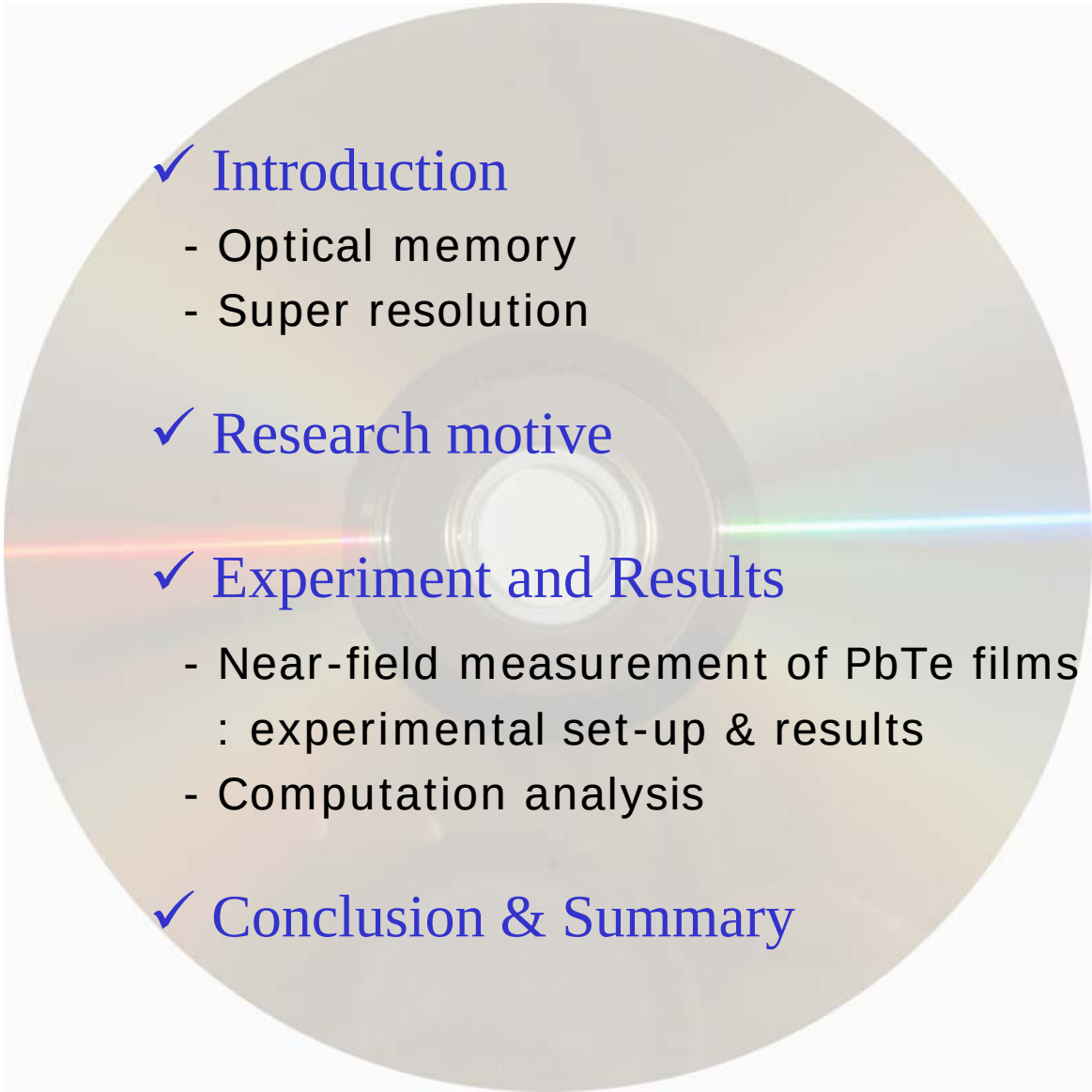
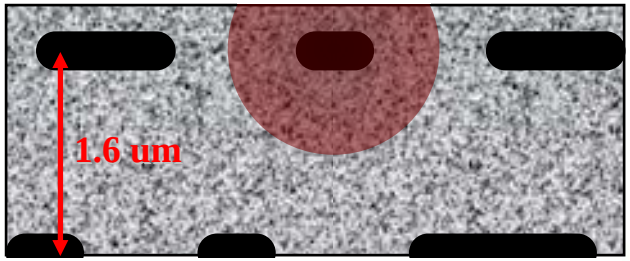
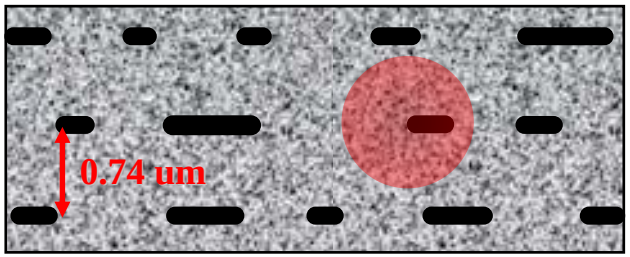


Optical memory

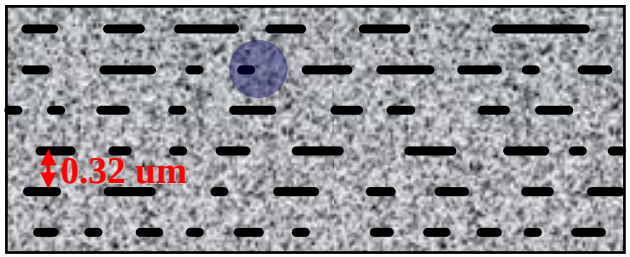
CD
- ✓ 0.65 GB
- ✓ NA 0.45
- ✓ λ = 780nm



DVD
- ✓ 4.7 GB
- ✓ NA 0.6
- ✓ λ = 650nm



Blu-ray
- ✓ 25 GB
- ✓ NA 0.85
- ✓ λ = 405nm



$$Density \propto \frac{NA}{\lambda}$$

✓ High density

→ Small pits & resolution

→ Optical diffraction resolution limit

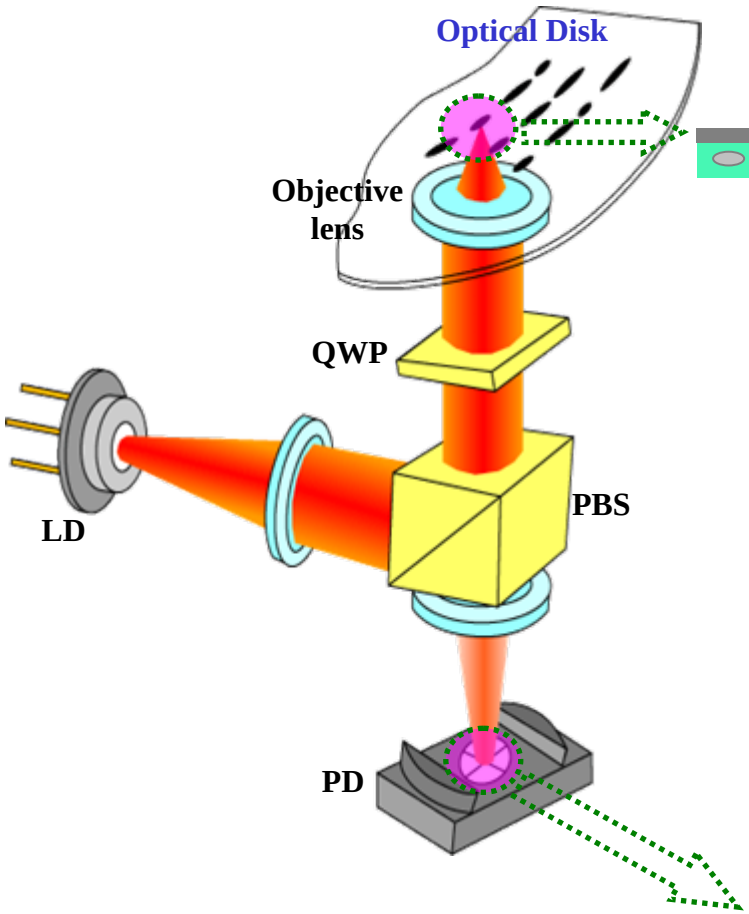
(λ / NA : wavelength / lens NA)

✓ Removibility

⇨ Super resolution

Diffraction limit NA : 1, Visible wavelength : 400 ~ 700 nm

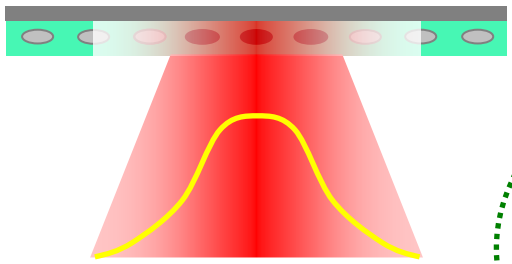
Super-resolution (SR)

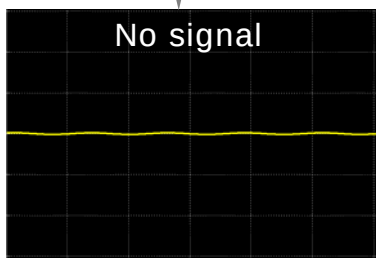


Laser beam spot

λ / NA

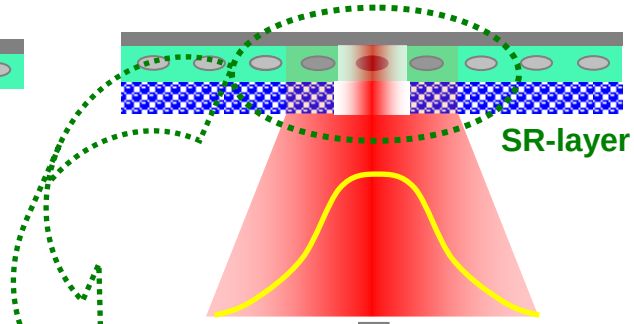
W/O SR-layer



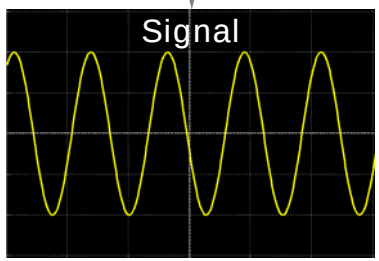


Spot > 2 x period

With SR-layer



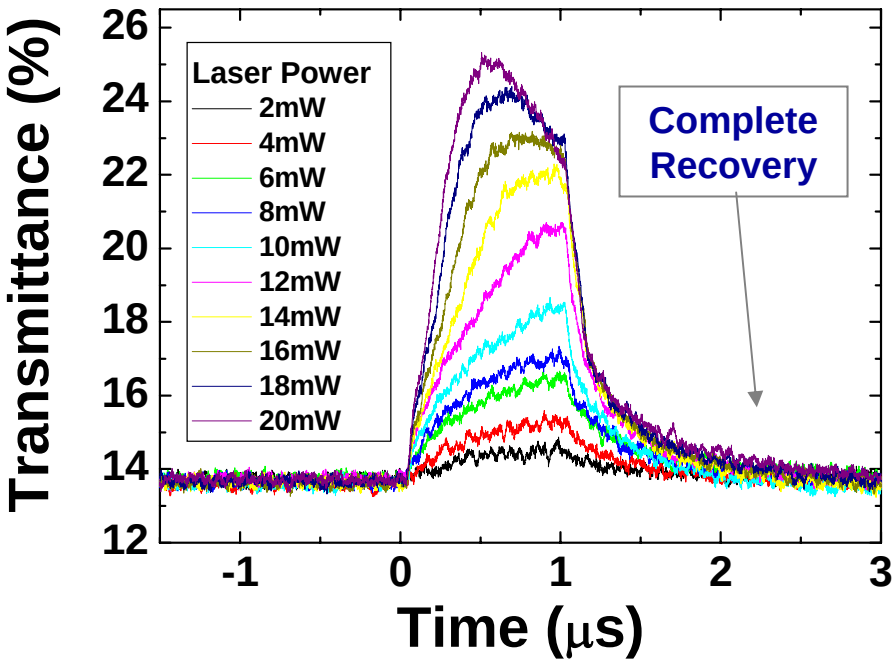
- ✓ Active Aperture
- ✓ Near-field coupling with pits



Spot < 2 x period

Research motive

- Optical Nonlinearity of PbTe



Far-field averaged intensity

✓ Active aperturing

⇨ Near-field intensity profile measurement

Near-field region

✓ Fast & large optical response.

✓ Complete recovery after laser beam off.

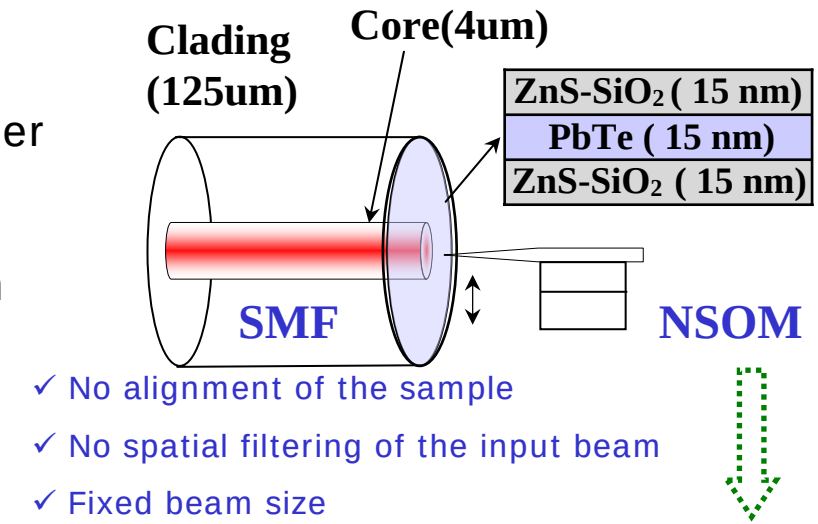
✓ SR mechanism

⇨ Computation analysis

- *H.S. Lee, et al, Appl. Phys. Lett, 85, 2782 (2004)*
- *H.S. Lee, et al, Surface & Coatings Tech. 193(2005) 335*
- *T.S. Lee, et al, J. Nanosci. Nanotechnol.(2006) ; to be published*

Sample preparation

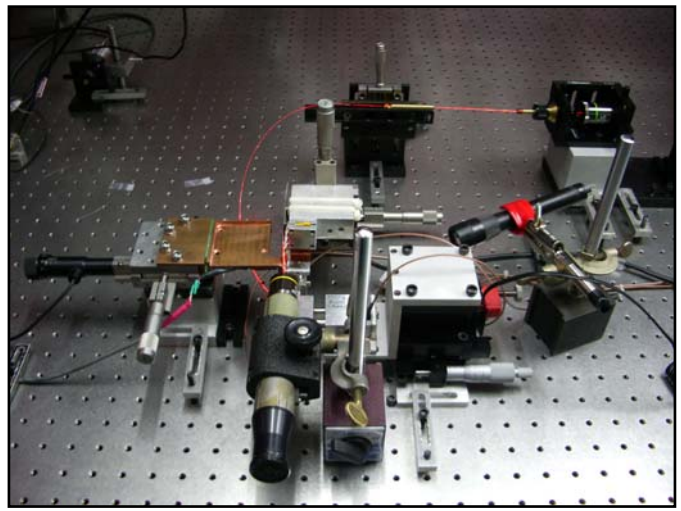
- Substrate : Cleaved facet single mode fiber
- Stack : ZnS-SiO_2 / PbTe / ZnS-SiO_2
- ZnS-SiO_2 : prevent oxidation of PbTe film
- RF magnetron sputtering method



✓ No alignment of the sample
✓ No spatial filtering of the input beam
✓ Fixed beam size

Measurement instrument

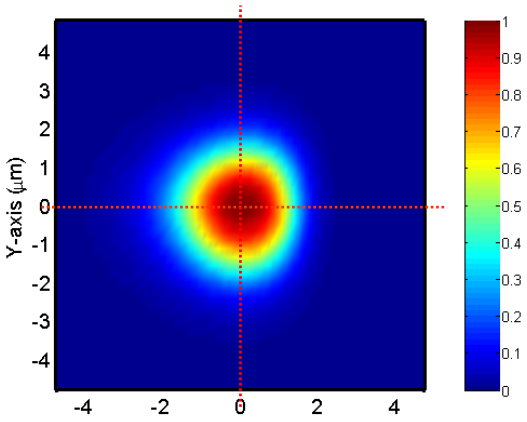
- Lab-made active feedback NSOM
- Tip aperture diameter : 100 nm
- Tip aperture coating : Al
- Tip - sample distance : < 20 nm
- Input beam : 632.8nm He-Ne laser(25mW)

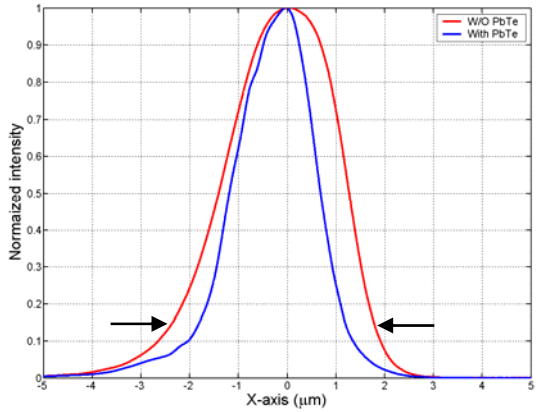


➢ *K.B. Song, et al, S.H. Park, Appl. Phys. Lett., p2260 (1998)*

NSOM Result : Comparison with bare fiber

Bare fiber

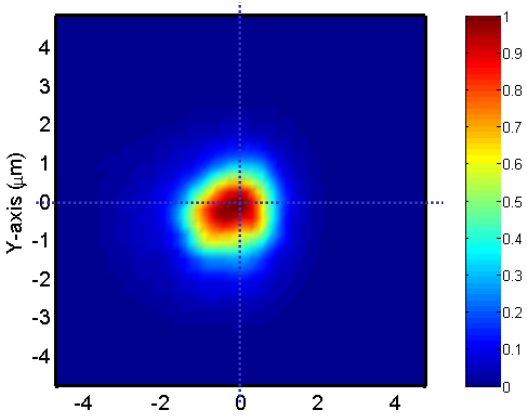


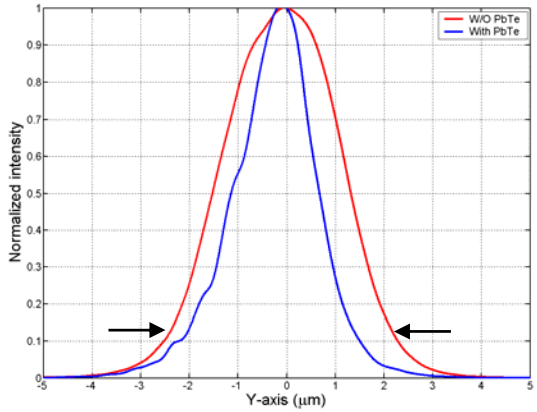


$1/e^2$ size

- ✓ Bare fiber : 4.25 um
- ✓ With PbTe : 3.08 um

With PbTe layer



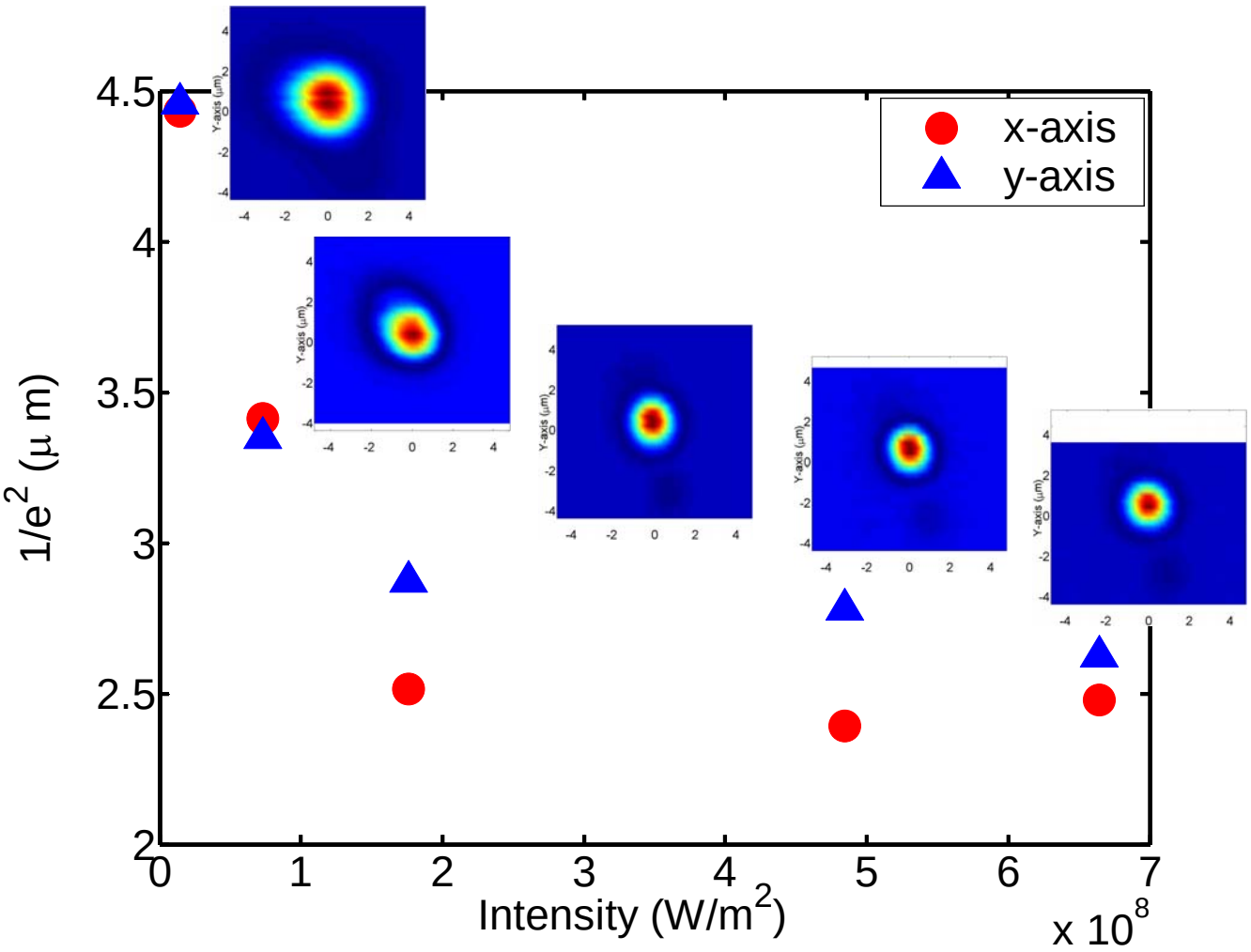


$1/e^2$ size

- ✓ Bare fiber : 4.49 um
- ✓ With PbTe : 3.35 um

⇨ Spot size was reduced in near-field region with the PbTe thin film !

NSOM measurement results : power dependency



⇨ Spot size reduction at the PbTe thin films in the near-field region is due to the intensity dependent optical nonlinear effect !

Finite Difference Time Domain (FDTD)

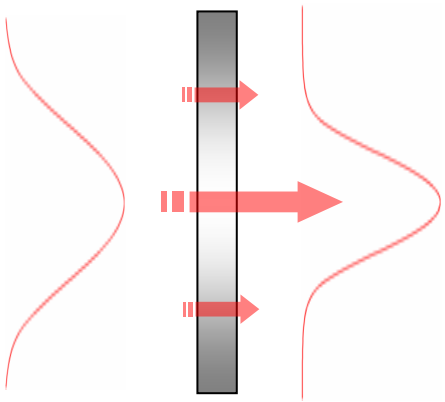
- ✓ Maxwell's eq. in differential form
- ✓ Whtiout approximation

} Full vector diffraction calculation method

$$\frac{\partial \vec{E}}{\partial t} = \frac{1}{\varepsilon}\left(\nabla \times \vec{H} - \sigma \vec{E}\right) \Rightarrow \begin{cases} \frac{\partial E_x}{\partial t} = \frac{1}{\varepsilon}\left[\frac{\partial H_z}{\partial y} - \frac{\partial H_y}{\partial z} - \sigma E_x\right] \\ \frac{\partial E_y}{\partial t} = \frac{1}{\varepsilon}\left[\frac{\partial H_x}{\partial z} - \frac{\partial H_z}{\partial x} - \sigma E_y\right] \\ \frac{\partial E_z}{\partial t} = \frac{1}{\varepsilon}\left[\frac{\partial H_y}{\partial x} - \frac{\partial H_x}{\partial y} - \sigma E_z\right] \end{cases}$$

$$\frac{E_x\Big|_{i,j+\frac{1}{2},k+\frac{1}{2}}^{n+\frac{1}{2}} - E_x\Big|_{i,j+\frac{1}{2},k+\frac{1}{2}}^{n-\frac{1}{2}}}{\Delta t} = \frac{1}{\varepsilon}\left[\frac{H_z\Big|_{i,j+1,k+\frac{1}{2}}^{n} - H_z\Big|_{i,j,k+\frac{1}{2}}^{n}}{\Delta y} - \frac{H_y\Big|_{i,j+\frac{1}{2},k+1}^{n} - H_y\Big|_{i,j+\frac{1}{2},k}^{n}}{\Delta z} - \sigma \frac{E_x\Big|_{i,j+\frac{1}{2},k+\frac{1}{2}}^{n+\frac{1}{2}} + E_x\Big|_{i,j+\frac{1}{2},k+\frac{1}{2}}^{n+\frac{1}{2}}}{2}\right]$$

Nonlinear optical properties in SR layer



SR layer

$$n\left(\vec{r}\right) = n_0 + n_2\left|\vec{E}\left(\vec{r}\right)\right|^2$$

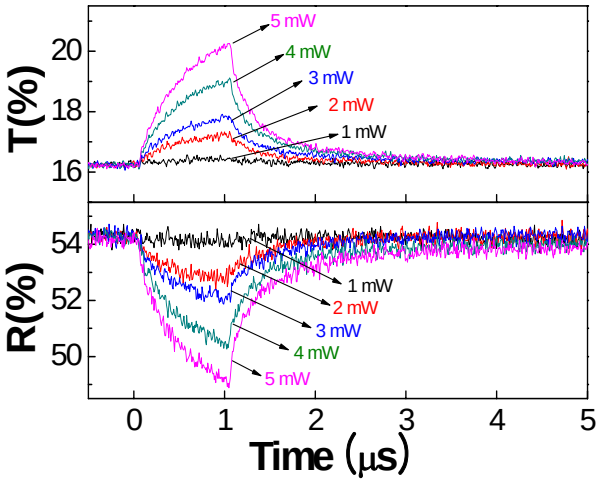
$$\kappa\left(\vec{r}\right) = \kappa_0 + \kappa_2\left|\vec{E}\left(\vec{r}\right)\right|^2$$

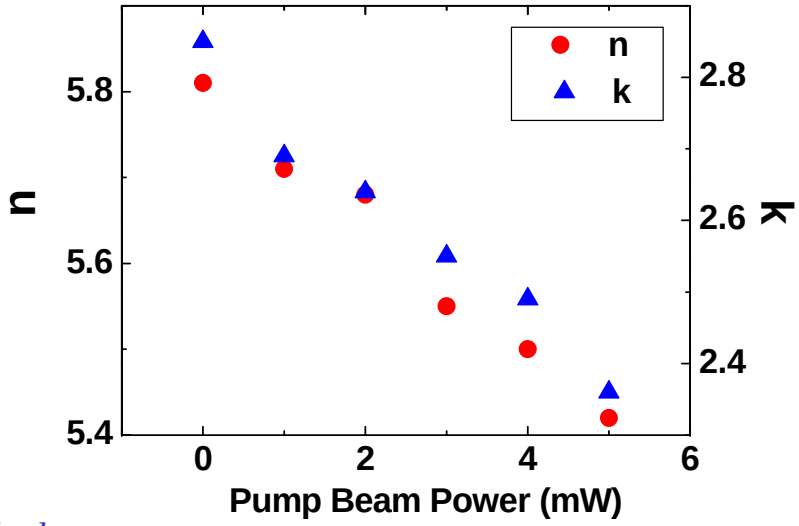
$$\left[\hat{n}(\omega)\right]^2 = \left[n(\omega) + i\kappa(\omega)\right]^2 = \frac{c^2}{\omega^2}k^2$$

$$= \varepsilon + i\frac{\sigma}{\varepsilon_0 \omega}$$

➢ Insideoptics™, *RayWiz-FDTD*

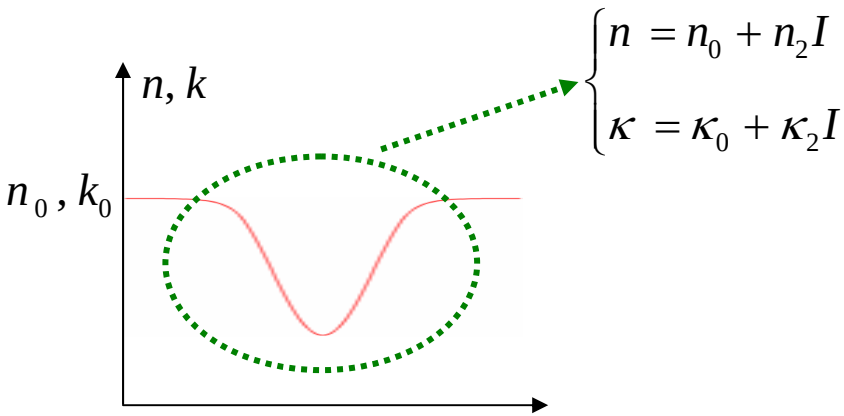
- Far-field real-time R/T results





➢ *T.S. Lee, et al. J. Nanosci. Nanotechnol.(2006) ; to be published*

- Nonlinear optical parameter for calculation



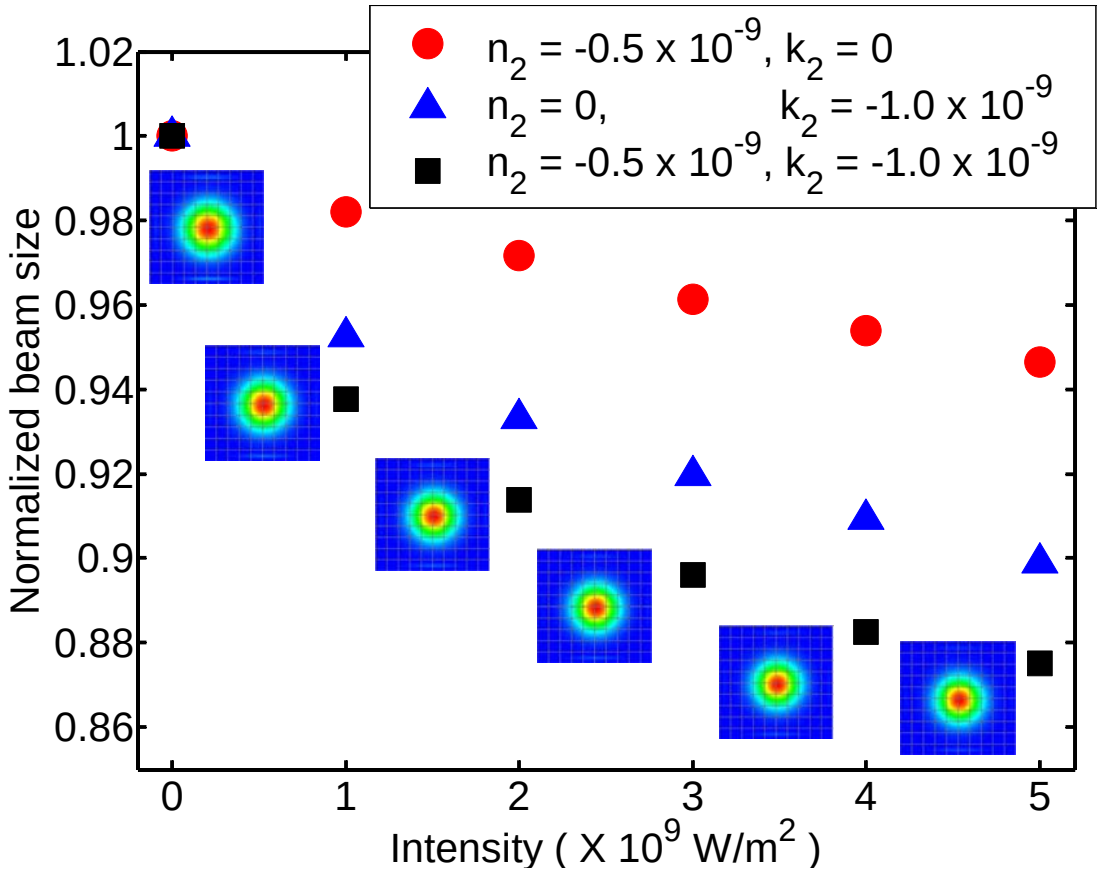
$$\begin{cases} n = n_0 + n_2 I \\ \kappa = \kappa_0 + \kappa_2 I \end{cases}$$

$$n = 5.8 - 0.5\times10^{-9}\ I$$

$$\kappa = 2.9 - 1.0\times10^{-9}\ I$$

$$I = 1.0\times10^{9}\ W/m^2$$

Simulation results



$$n = n_0 + n_2 I$$

$$\kappa = \kappa_0 + \kappa_2 I$$

$$I = 1.0 \times 10^9 \; W/m^2$$

➢ Insideoptics™, *RayWiz-FDTD*

⇨ Nonlinear optical properties affect the reduction of the spot size !

⇨ When the laser beam illuminate to the PbTe thin film, saturable absorption dut to reduction k and reduction in refractive index are derived !

Conclusion & Summary

- ✓ Near-field intensity profile of PbTe thin films are measured with NSOM.
- ✓ From the experimental result, it was found that spot size in the vicinity of PbTe material was reduced with no abrupt beam profile change.
- ✓ In the computational analysis, a phenomenological nonlinear optical model is developed within the framework of a FDTD method.
- ✓ Simulation results shows that optical properties of the PbTe thin film depend on the input laser intensity, and the reduction of the spot size in the near-field region is due to refractive index and extinction coefficient both.

Thank you very much for your kind attention.