Advanced fundamental of OSLO

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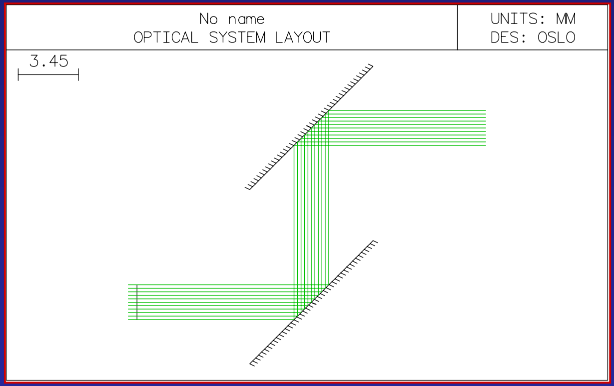
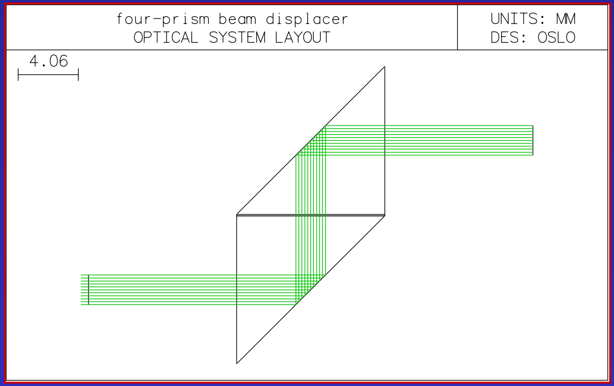
- Global optimization
- Non-sequential ray tracing
- Diffraction optics
- Gaussian beam
- Polarization calculation

Example 2
Four-prism configuration beam displacer
(achromatic polarization-preserving)

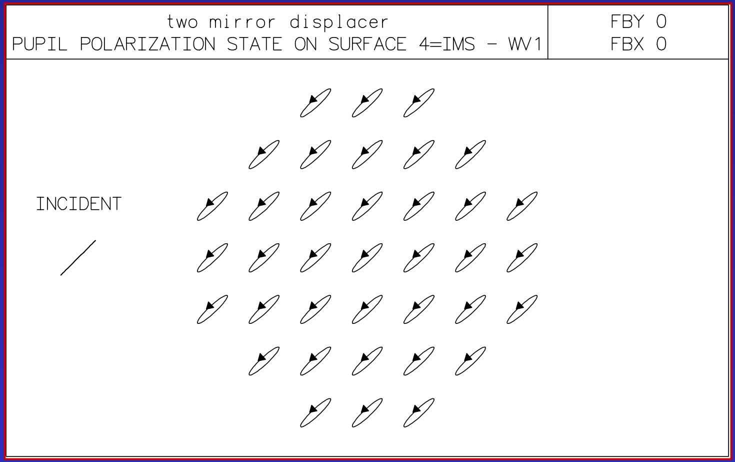
Introduction to beam displacer

- Traditional beam displacer





- If it requires that linear polarization be preserved, then these two system will work only if the state of polarization is *p*- or *s*-polarization.



Phase delay

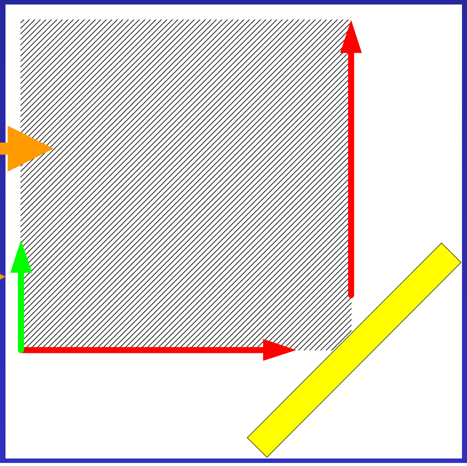
- Definition
  - *p*-polarization : the polarization which is parallel to the incident plane.
  - *s*-polarization : the polarization which is perpendicular to the incident plane.

- The relative phase shift after total internal reflection

$$\boxed{\delta = \delta_p - \delta_s} \Rightarrow \boxed{\tan\frac{\delta}{2} = \frac{\cos\theta_i\sqrt{\sin^2\theta_i - n^2}}{\sin^2\theta_i}}$$

Incident plane

***p*-polarization**



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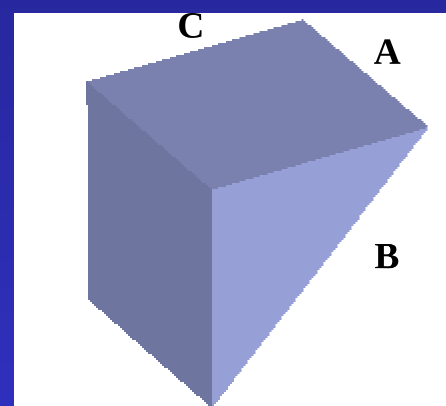
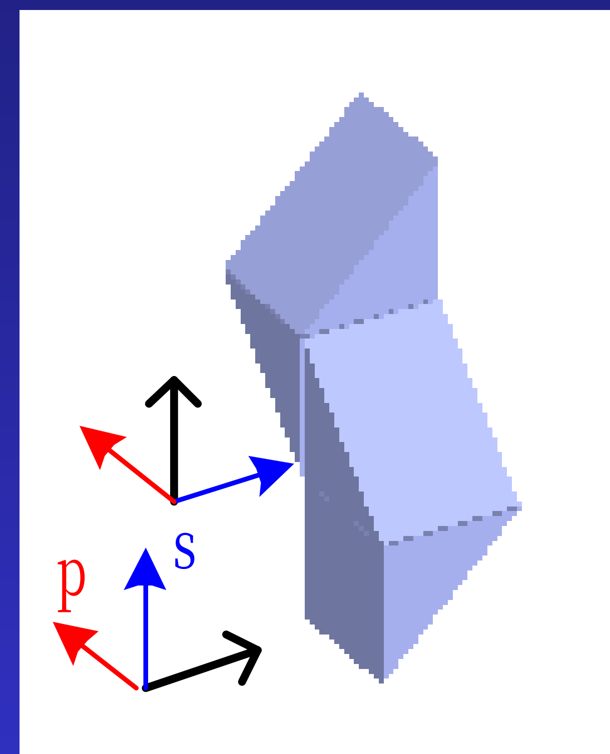
Specification

- Prism
  - Size :
    - A= 10 mm
    - B= 14 mm
    - C= 10 mm
  - Material : BK7
  - The four prisms are cemented together with refractive index-matching epoxy.





Procedure

- Step 1: building the system
  - specifying the layout of the system.
  - Defining the parameter of these prisms.

- Step 2 : polarization ray tracing

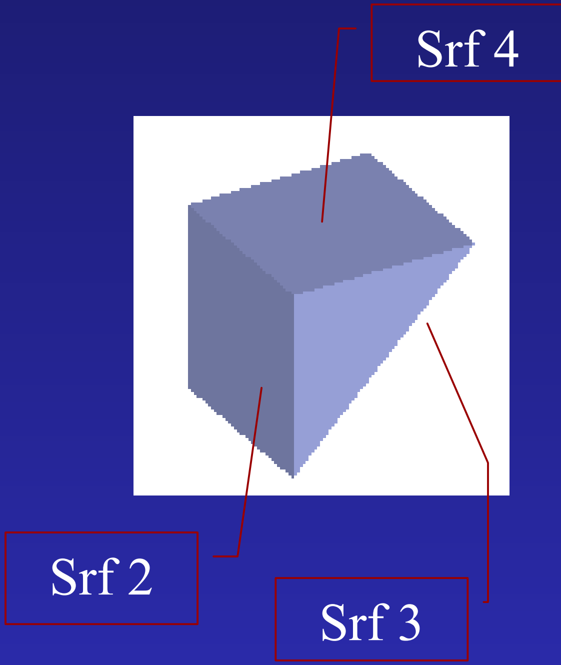
Building the prism

1. Using the "special aperture data" to define the rectangular shape aperture of each surface.

2. Srf 3 and Srf 4 should define the surface tilting and decenter.

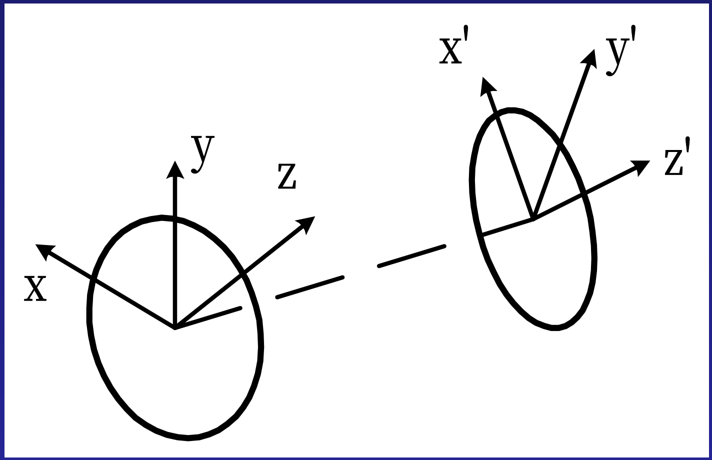
3. We define "total internal reflection" on Srf 3.

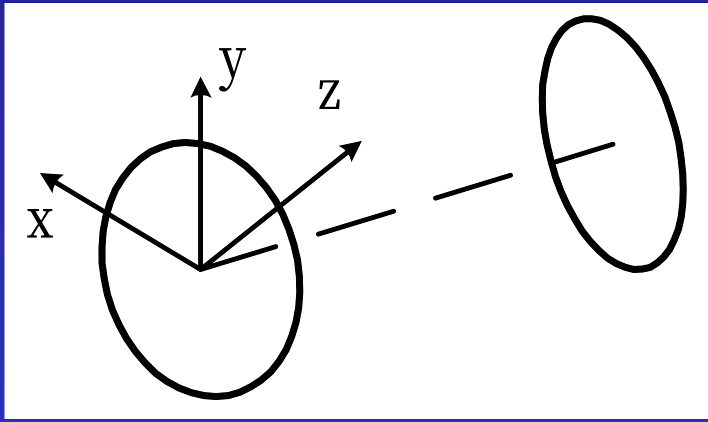
4. We also define "anti-reflecting coatings" on Srf 2 and Srf 4.



Surface coordinate

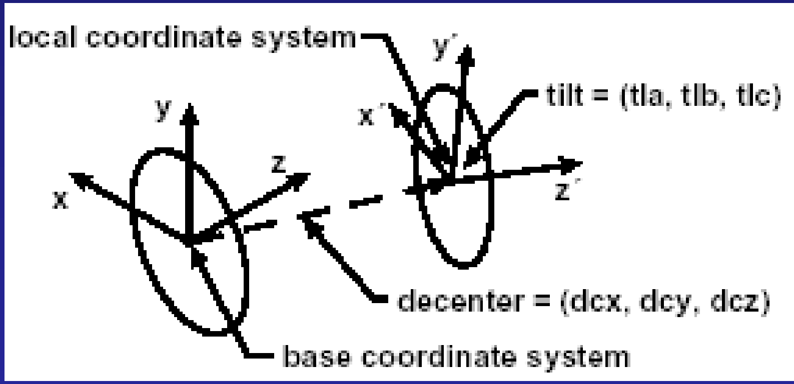
- Local coordinate
  - Each surface is described in a local coordinate system, whose origin is relative to a base coordinate system for that surface.
- Global coordinate
  - The coordinate at each surface relates to the base coordinate system of the global reference surface.

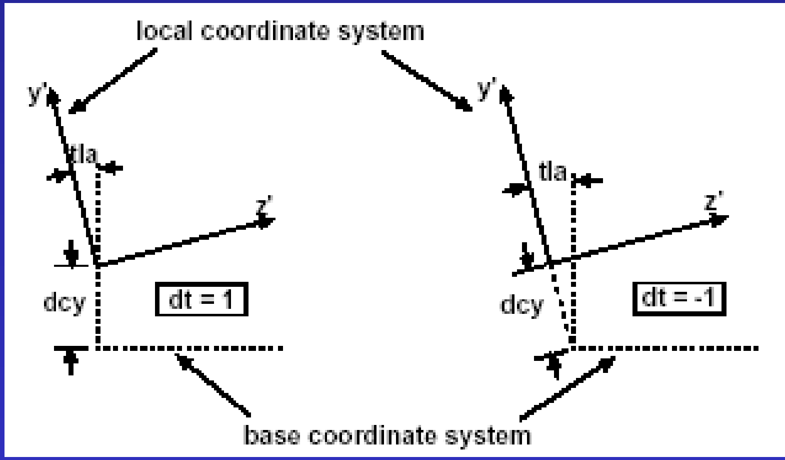




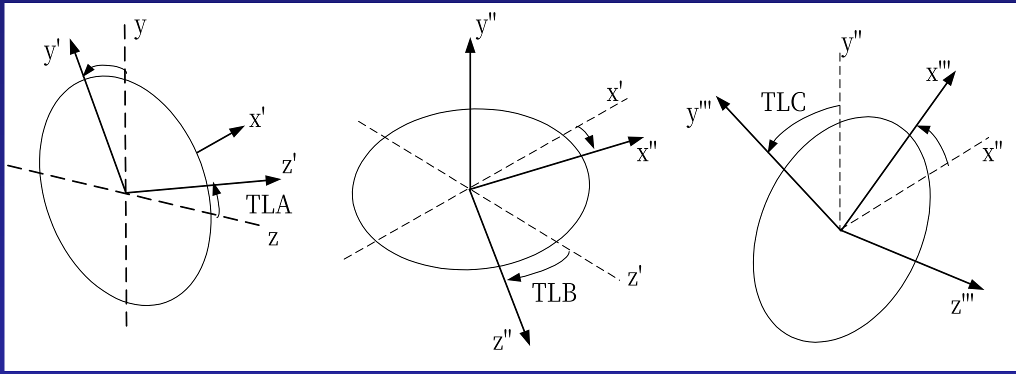
Surface coordinate

- Surface tilt and decenter

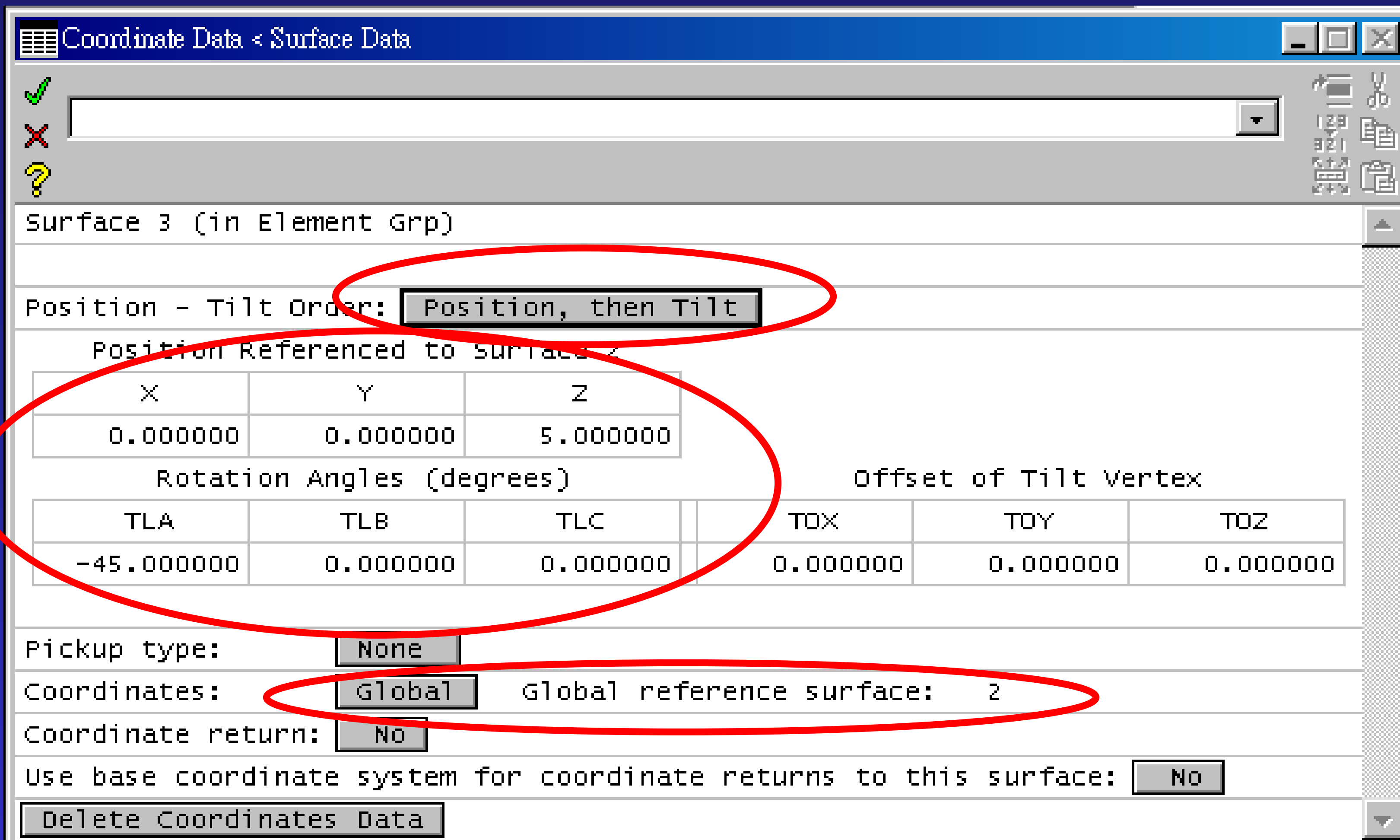




- The definition of TLA, TLB and TLC.



Defining surface coordinates



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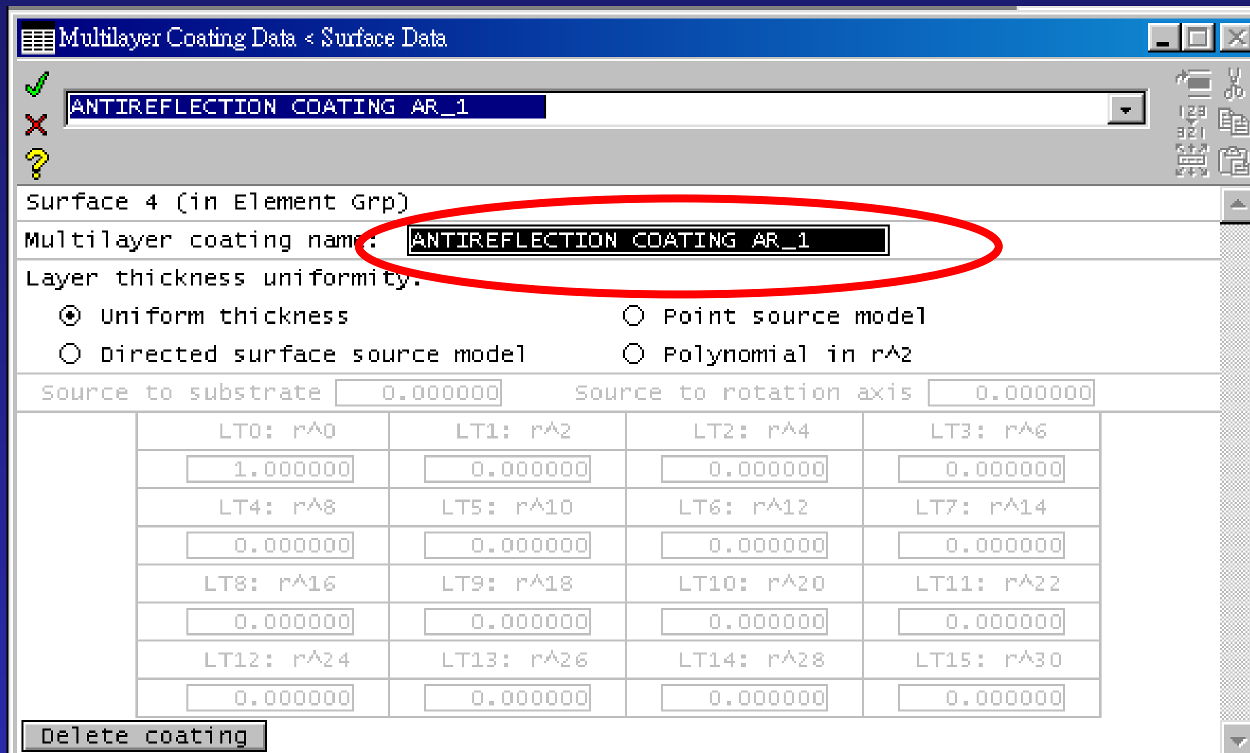
Setting anti-reflection coatings

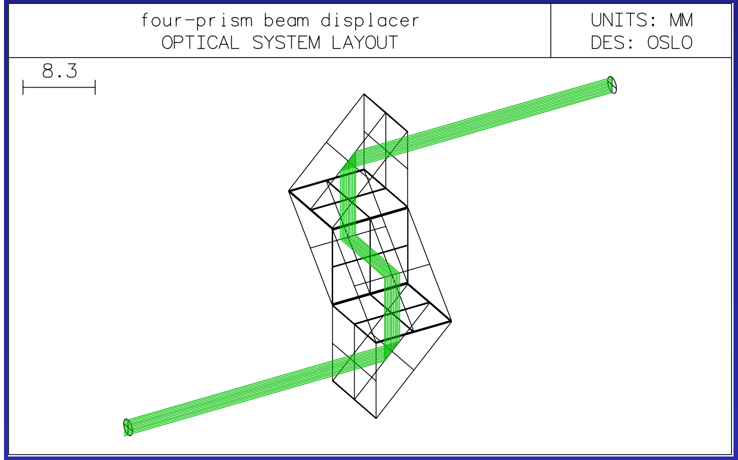



```
*MULTILAYER COATING DATA - ANTIREFLECTION COATING AR_1
 REFERENCE WAVELENGTH IN AIR:     0.520000 MICROMETERS
 LAYER THICKNESSES ARE MICROMETERS (OPTICAL THICKNESS)
 LAYER ORDERING: SUBSTRATE TO INCIDENT MEDIUM
 LAYER   THICKNESS   MATERIAL/INDEX  EXTINCT COEF
   1       0.130000          MGF2
```

Surface data and system feature

*LENS DATA
four-prism beam displacer

SRF	RADIUS	THICKNESS	APERTURE RADIUS	GLASS	SPE	NOTE
OBJ	--	1.0000e+20	1.0000e+14	AIR		
AST	--	30.000000	1.000000 AS	AIR	*	
2	--	--	1.000030 SX	N-BK7 C	*	
3	--	--	1.000033 SX	AIR	*	
4	--	--	1.000033 SX	AIR	*	
5	--	-0.100000	1.000033 SX	N-BK7 P		
6	--	--	1.000033 SX	N-BK7 P	*	
7	--	--	1.000037 SX	AIR	*	
8	--	--	1.000037 SX	AIR	*	
9	--	0.100000	1.000037 SX	N-BK7 P		
10	--	--	1.000037 SX	N-BK7 P	*	
11	--	--	1.000040 SX	AIR	*	
12	--	--	1.000040 SX	AIR	*	
13	--	-0.100000	1.000040 SX	N-BK7 P		
14	--	--	1.000040 SX	N-BK7 P	*	
15	--	--	1.000043 SX	AIR	*	
16	--	30.000000	1.000043 SX	AIR	*	
17	--	--	1.000073 S	AIR	*	
IMS	--	--	1.000073 S			

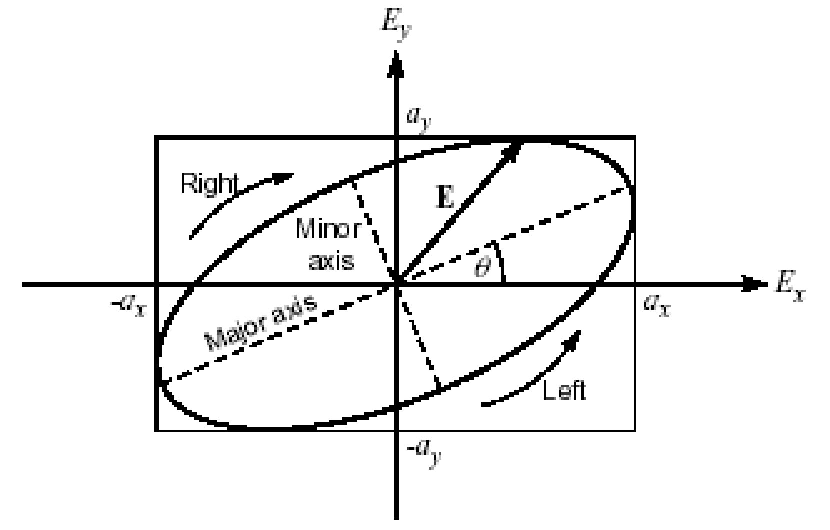


Polarization calculation

- OSLO using Fresnel equations to calculate the polarization state being tracing through an optical system.

- Ellipse polarization

$$E_x = a_x \cos(\omega t - \vec{k} \bullet \vec{r} + \delta_x)$$
$$E_y = a_y \cos(\omega t - \vec{k} \bullet \vec{r} + \delta_y)$$



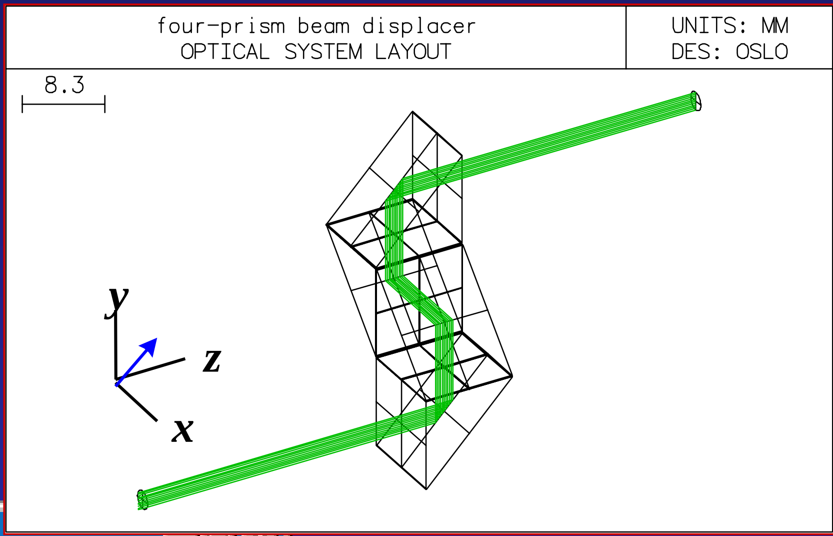
  – Polarization ellipse :
    e = minor axis / major axis

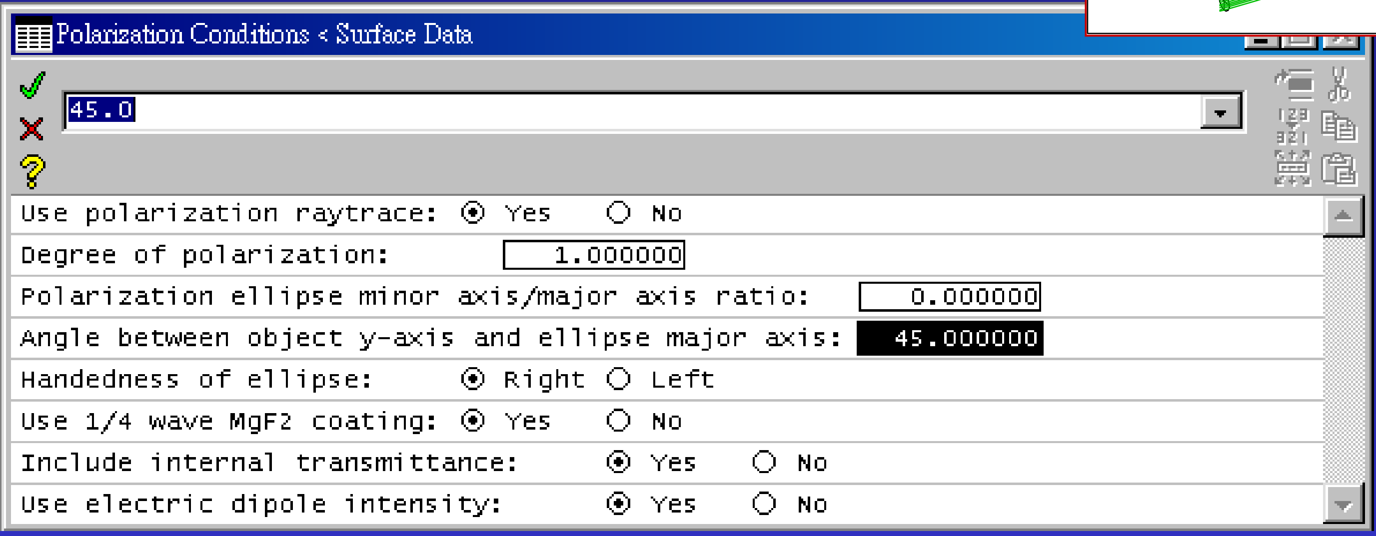
$$\tan 2\theta = \frac{2a_x a_y}{a_x^2 - a_y^2} \cos\delta$$

$$\delta = \delta_y - \delta_x$$

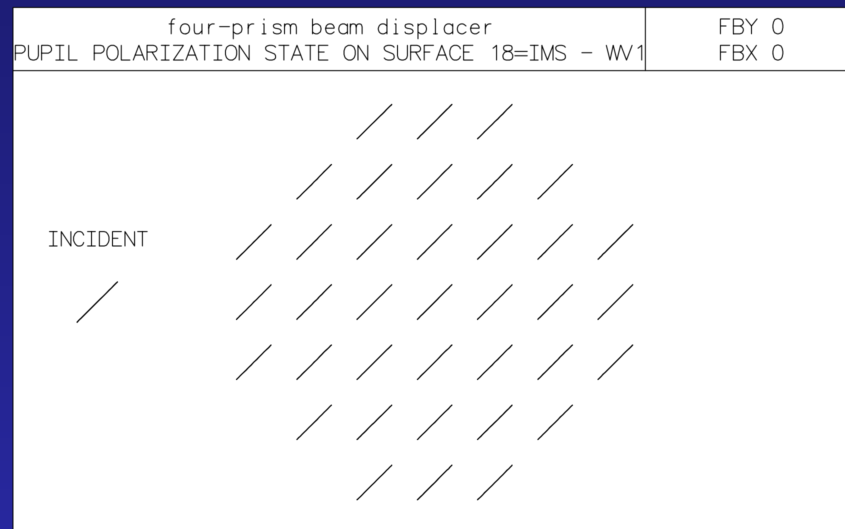
Defining the initial polarization state

- We assume the initial polarization is perfect linear which has a 45 degree angle relative to the y axis.





Evaluate final state of polarization




```
*TRACE RAY - LOCAL COORDS - FBY  0.00, FBX  0.00, FBZ  0.00
 SRF         Y/L          X/K          Z/M       YANG/IANG   XANG/RANG       D/OPL
          INTENSITY   DEG. POLRZ. ELL. RATIO   ELL. ANGLE   HANDEDNESS

 18      -1.8326e-14 -1.4293e-14       --      -1.8779e-14 -1.8779e-14       --
         -3.2775e-16 -3.2775e-16    1.000000       --       2.6557e-14  121.058095
            0.855404    1.000000 9.5684e-17    45.000000       LEFT =   -1.000000
 PUPIL        FY           FX          RAY AIMING                           OPD
              --           --        CENTRAL REF RAY                         --
```

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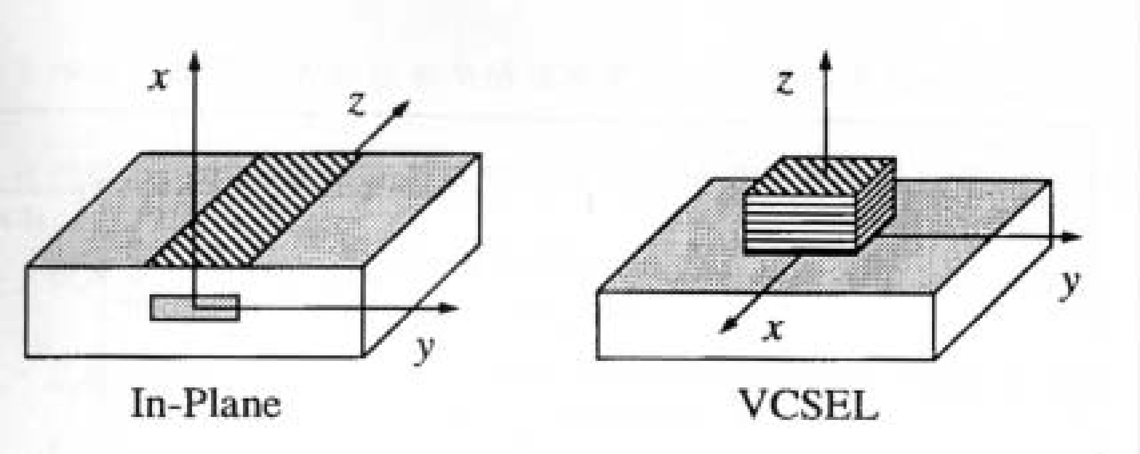
Example 3
Effective lens model of VCSEL

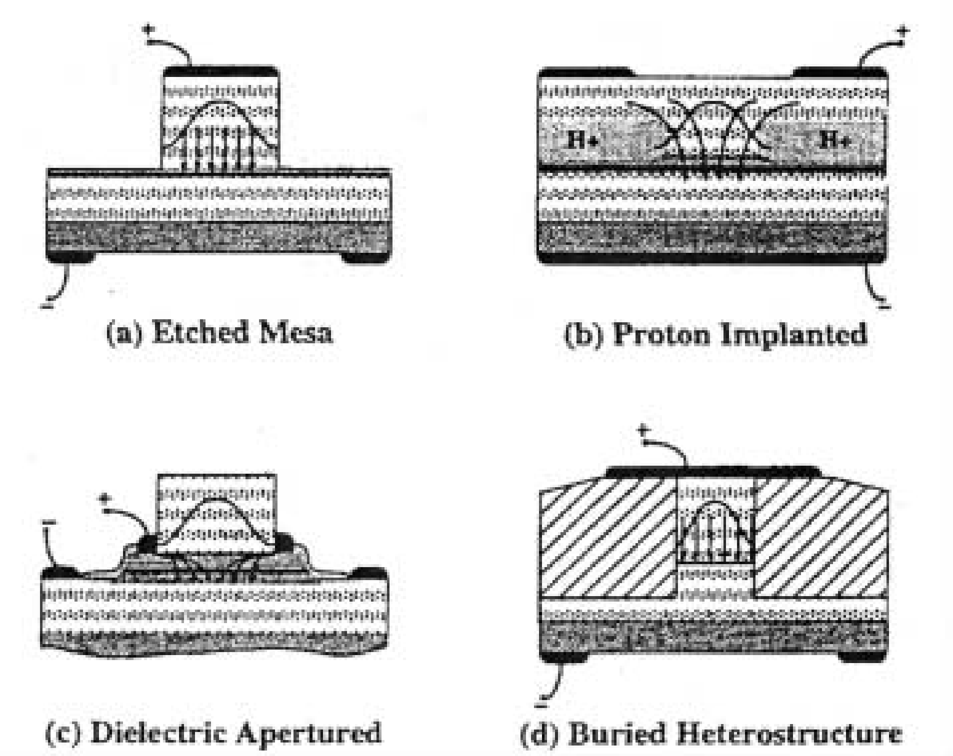
Introduction of VCSEL

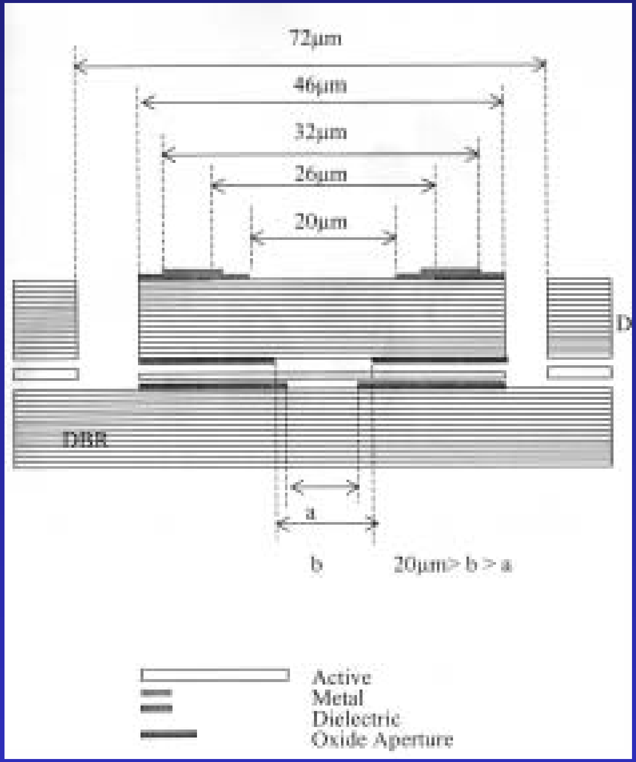
- VCSE: Vertical Cavity Surface Emitting Lasers
- VCSEL is a kind of semiconductor lasers. But unlike common semiconductor lasers, it emits laser light vertically.
- Since the cavity is cylindrical shape, the emission mode of VCSEL is also in symmetrical shape. Nevertheless, VCSEL also can emit donut-like field pattern (whispering gallery mode)



Introduction of VCSEL

- The construction of VCSEL





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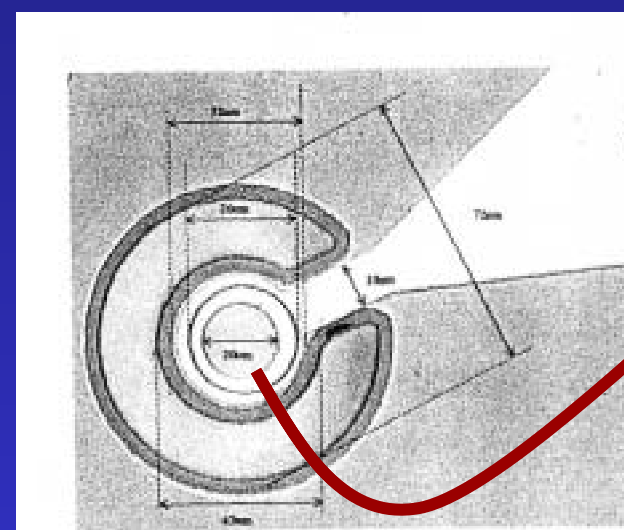
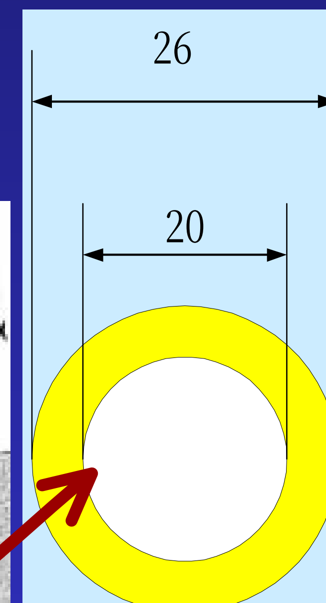
Specification

- We would like to build an effective lens model to simulate a VCSEL with donut-like field pattern.
- Furthermore, we would like to evaluate the coupling efficiency with fiber. Let us have the specification first.
  - Wavelength : 850 nm
  - Laser diode :
    - Emitting area
      - Outside circle diameter : 26 μm
      - Inside circle circle : 20 μm
    - Half-Divergence angle : 8 degree
  - Fiber:
    - Core~ 5 um
    - N.A.~ 0.3





Classification and Question

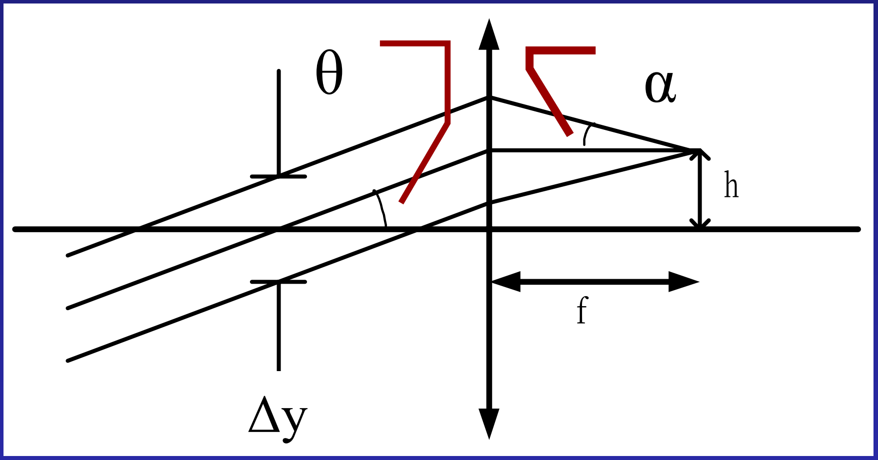
- Typical LD (semiconductor lasers)
  - Astigmatic sources to simulate elliptic Gaussian mode
    - Two point sources separated by an astigmatism distances.
- Typical VCSEL
  - Using point source with Gaussian ray tracing to simulate the perfect Gaussian mode
- Question
  - How to simulate Donut-pattern VCSEL?

Algorithm

- The modified model

$$\boxed{f = h\tan\theta}$$

$$\boxed{\tan\alpha = \frac{\Delta y}{2f}}$$



  - α :divergence angle
  - h: radius of emitting area
  - f: focal length of perfect length
  - θ: field angle of the defined object
  - Δy :diameter of defined aperture

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Calculation

- Divergence angle α=8 degree
- Emitting area radius
  - outside circle :h=0.013 mm
  - inside circle : h'=0.01 mm
- Focal length of perfect lens: 1mm

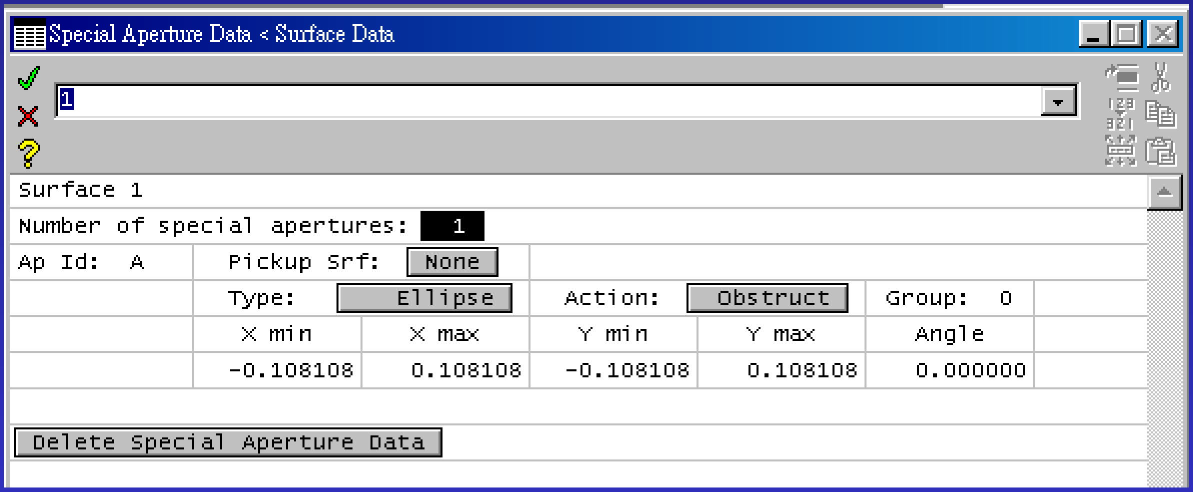
$f = h \tan \theta$ → θ=0.744803178 degree

$\tan \alpha = \frac{\Delta y}{2f}$ → Δy=0.140540834 mm

$\frac{h}{h'} = \frac{\Delta y}{\Delta y'}$ → Δy'=0.108108333 mm

Building effective lens model of VCSEL

- Step 1:Defining the aperture
  - Set the ring aperture on Srf 1 , enter Δy as the aperture radius and define it as the aperture stop.
  - Click the “Special Aperture Data” menu on Srf 1 , select “Obstruct” and enter Δy'.as the boundary.



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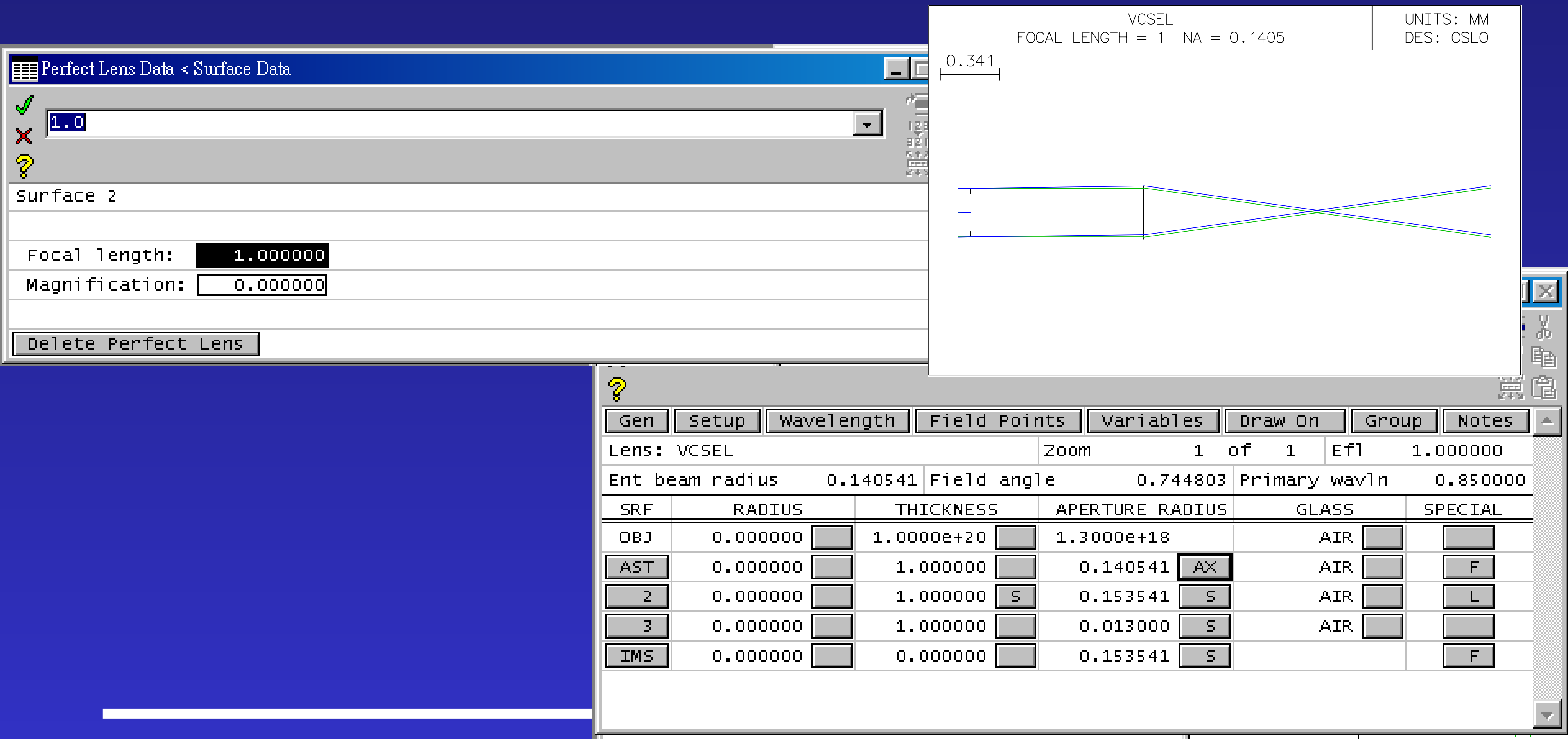
Building effective lens model of VCSEL

- Step 2: Build the perfect lens
  - Click “Perfect lens” on the “Special” button, enter focal length.



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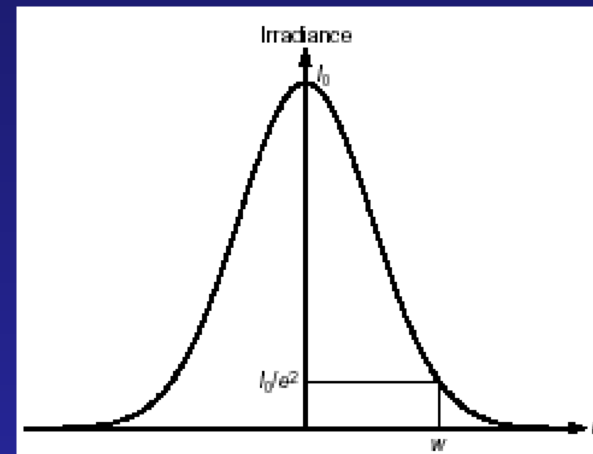
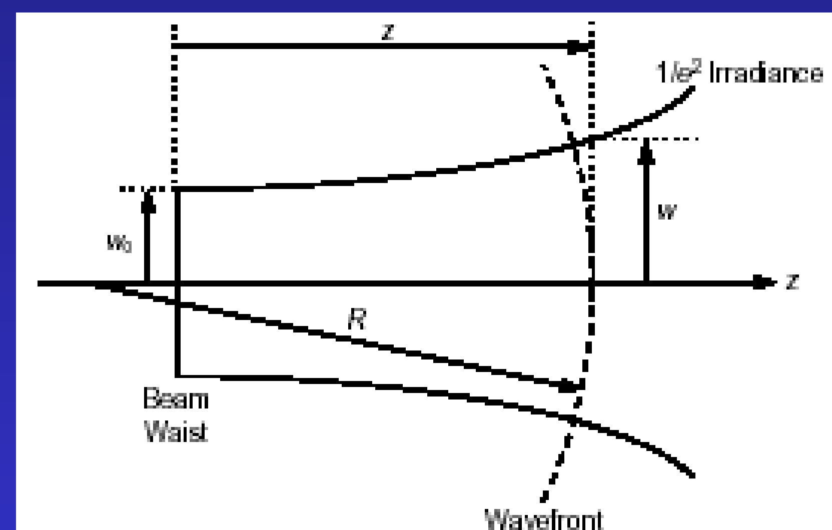
Guassian beam ray trace

- The algorithm is ABCD matrix.
- The formula of ω(z) and R(z).

$$^{2}(z) = \omega_0^2\left[1+\left(\frac{\lambda}{\pi\omega_0^2}\right)^2\right]$$

$$R(z) = z\left[1+\left(\frac{\pi\omega_0^2}{\lambda z}\right)^2\right]$$





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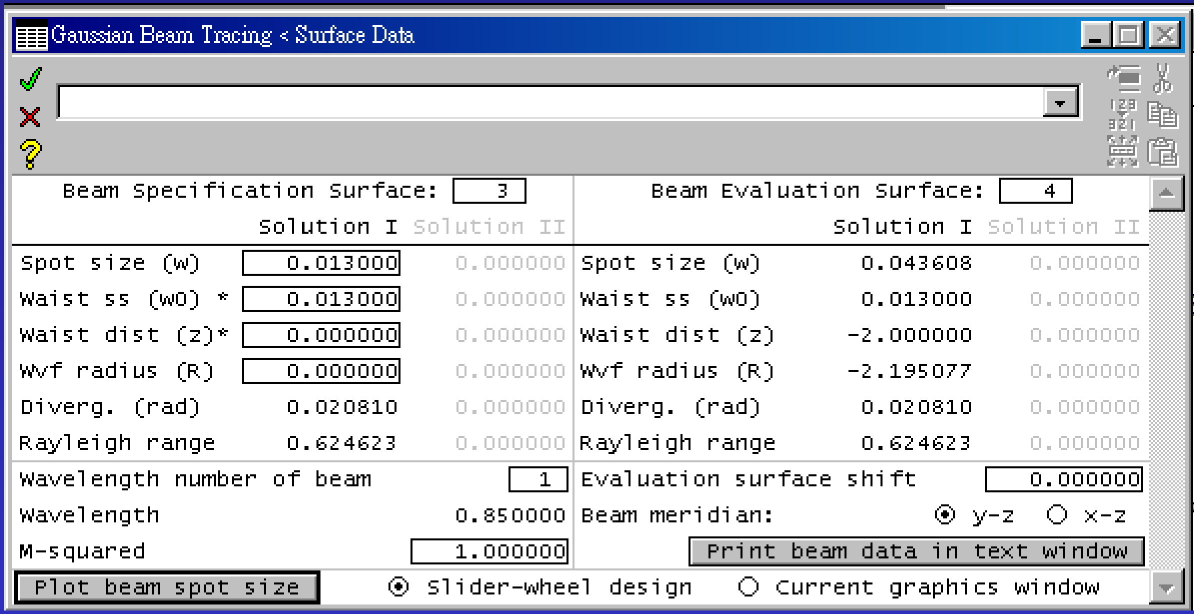
Guassian beam ray trace

- Step 1 : observing Guassian beam propagation
  1. Use “Source >> Paraxial Guassian Beam(ABCD)”.
  2. We should specify a surface to be a reference surface in calculation.
  3. Enter parameters which could define a guassian beam.



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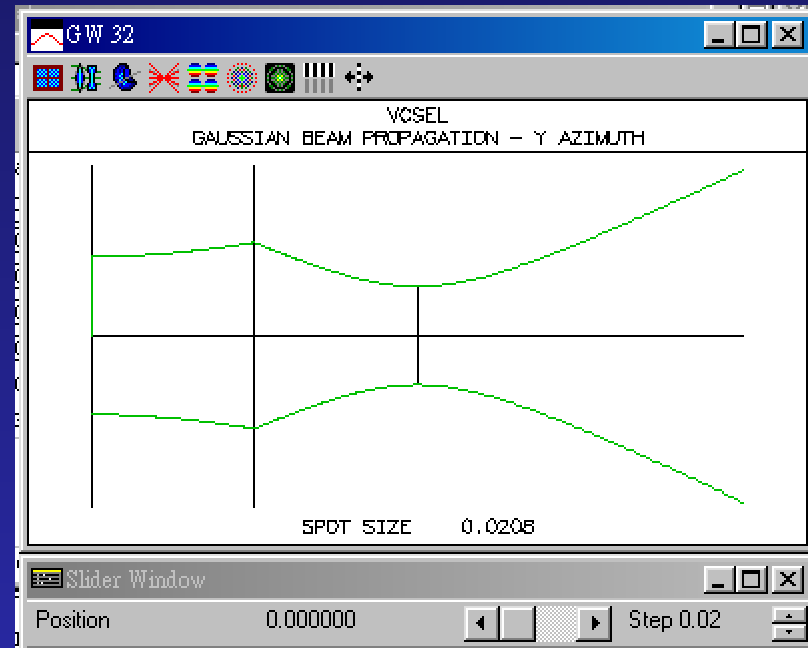
Observing Guassian beam propagation

- We could choose the "Plot beam spot size" to observe the graphical Guassian beam propagation or "Print beam data in text window" to check the Guassian beam on each surface.

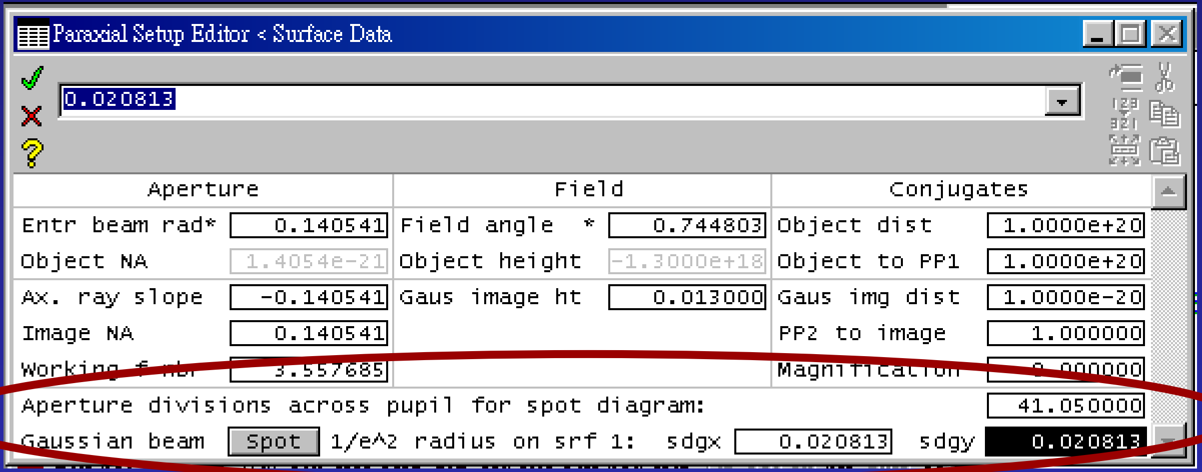


*GAUSSIAN BEAM - YZ PLANE
WAVELENGTH = 0.850000 M-SQUARED = 1.000000

SRF	SPOT SIZE	DIVERGENCE	WAIST SIZE	WAIST DIST	INC RADIUS	RFR RADIUS	RAYLEIGH RG
INC	0.020813	0.012999	0.020813	--	--	--	1.600967
1	0.020813	0.012999	0.020813	--	--	--	1.600967
2	0.024539	0.020810	0.013000	1.000000	-3.563095	1.390153	0.624623
3	0.013000	0.020810	0.013000	--	--	--	0.624623
4	0.043608	0.020810	0.013000	-2.000000	-2.195077	-2.195077	0.624623

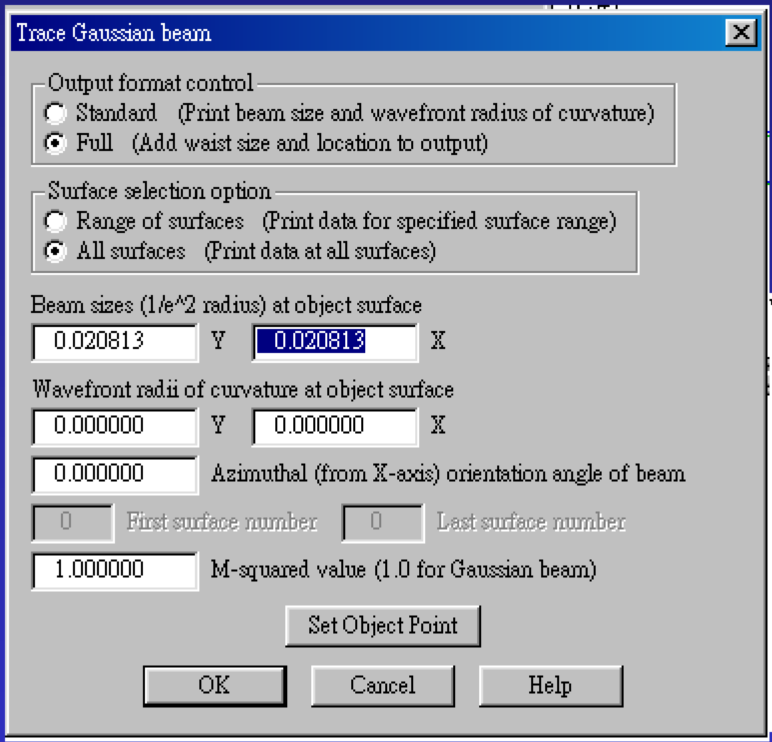
Guassian beam ray trace

- Step 2: setting Guassian beam
  - We set the “1/e^2 radius on Srf 1” equal to Guassian beam spot size on Srf 1 obtained by step 1.



Guassian beam ray trace

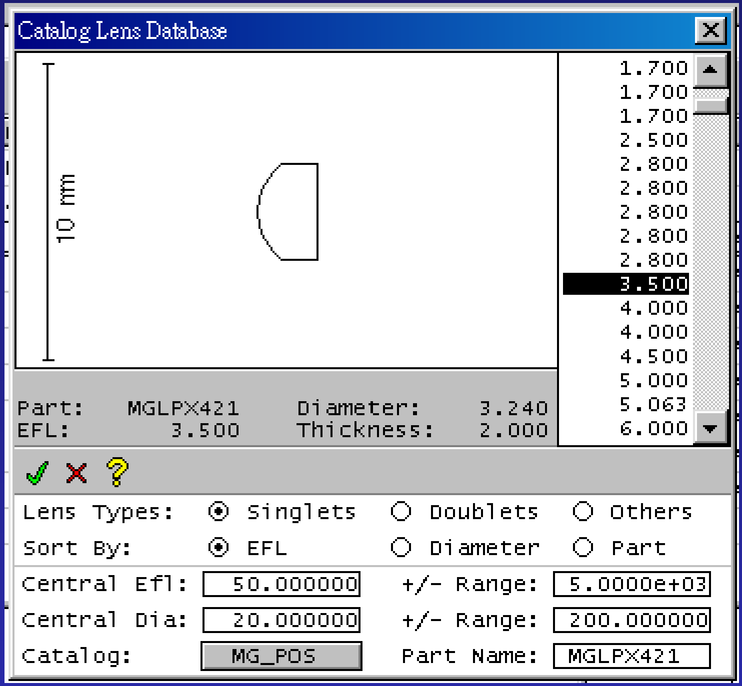
- Step 3: Guassian beam ray trace




```
*TRACE GAUSSIAN BEAM
 WAVELENGTH =     0.850000        M-SQUARED =     1.000000
 SRF       Y SPT SIZE   X SPT SIZE   BEAM AZMTH    Y RFR RAD    X RFR RAD  PHASE  AZMTH
           Y WST SIZE   X WST SIZE                 Y WST DST    X WST DST
 INC         0.020813     0.020813       --            --           --            --
             0.020813     0.020813                     --           --

  1          0.020813     0.020813       --       -1.8327e+13  -1.8327e+13        --
             0.020813     0.020813                -1.3987e-13  -1.3987e-13

  2          0.024539     0.024539       --          1.390121     1.390121        --
             0.013000     0.013000                   1.000000     1.000000

  3          0.013000     0.013000       --       -5.6026e+09  -5.6026e+09        --
             0.013000     0.013000                -6.9632e-11  -6.9632e-11

  4          0.024539     0.024539       --         -1.390121    -1.390121        --
             0.013000     0.013000                  -1.000000    -1.000000
```

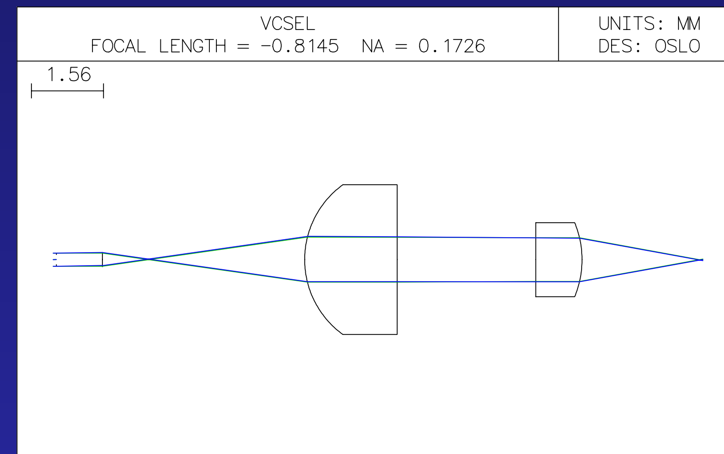
Build a collimating lens

- We could use the "catalog lens" to build a focusing lens.
- Right-clicking on Srf 4 and select insert "catalog lens".
- Select the part number "MGLPX421" on the "MG_POS" catalog.



Set focus lens

- Since the numerical aperture of fibers is 0.3, we can choose any focusing lens with numerical aperture smaller than 0.3.
- We design a focusing lens with diameter 1.6mm, numerical aperture 0.29 and SF4 material.



VCSEL

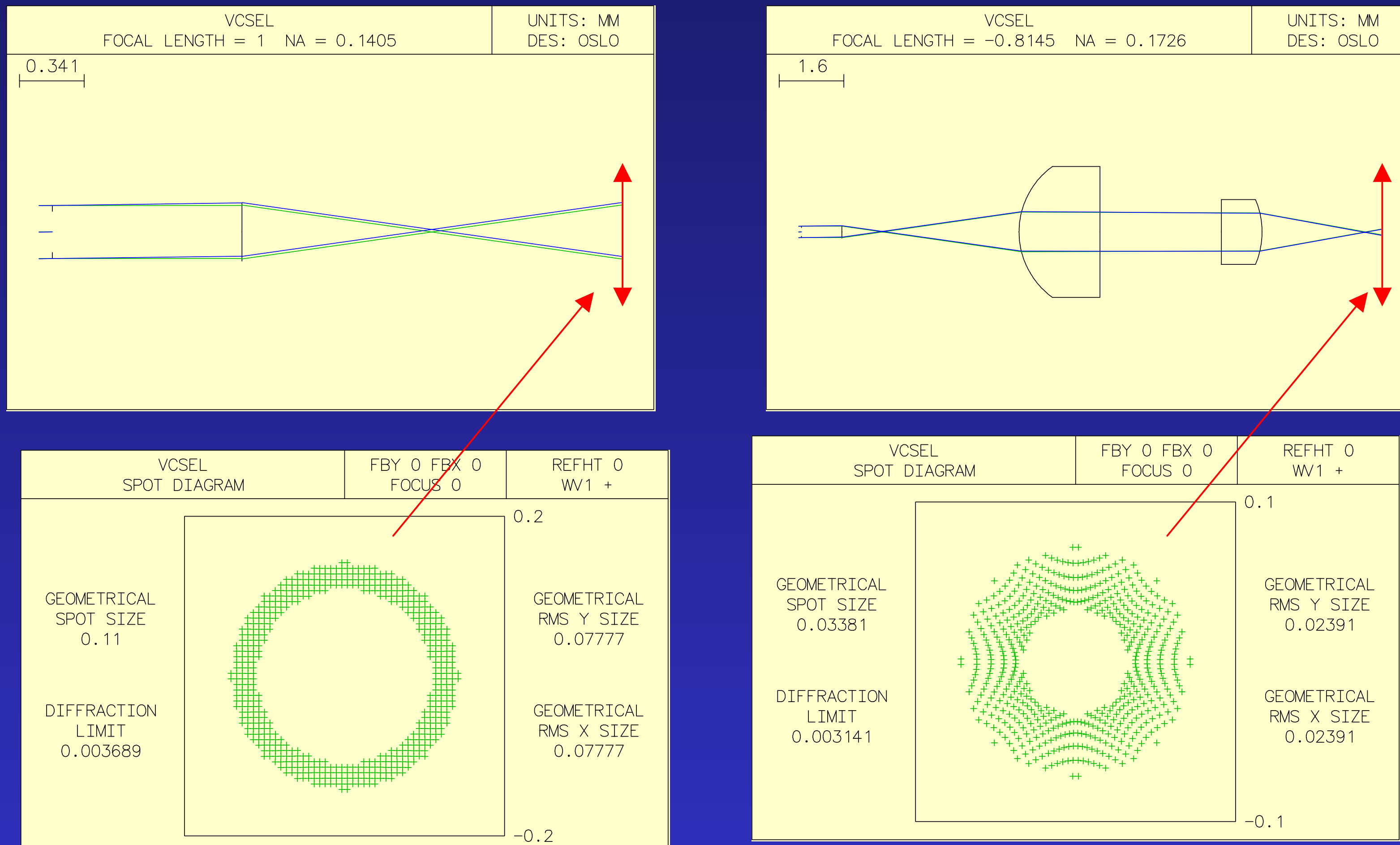
Collimating lens

focusing lens

*LENS DATA
VCSEL

SRF	RADIUS	THICKNESS	APERTURE RADIUS	GLASS	SPE	NOTE
OBJ	--	1.0000e+20	1.3000e+18	AIR		
AST	--	1.000000	0.140541 AX	AIR	*	
2	--	1.000000 S	0.153541 S	AIR	*	
3	--	3.376244	0.013000 S	AIR		
4	MGLPX421 F	2.000000 F	1.620000 F	FIXED F	*	
5	F	3.000000	1.620000 F	AIR		
6	--	1.000000	0.800000	SF4 C		
7	-2.080000	2.620000	0.800000	AIR		
IMS	--	--	0.066043 S		*	

Simulation Result



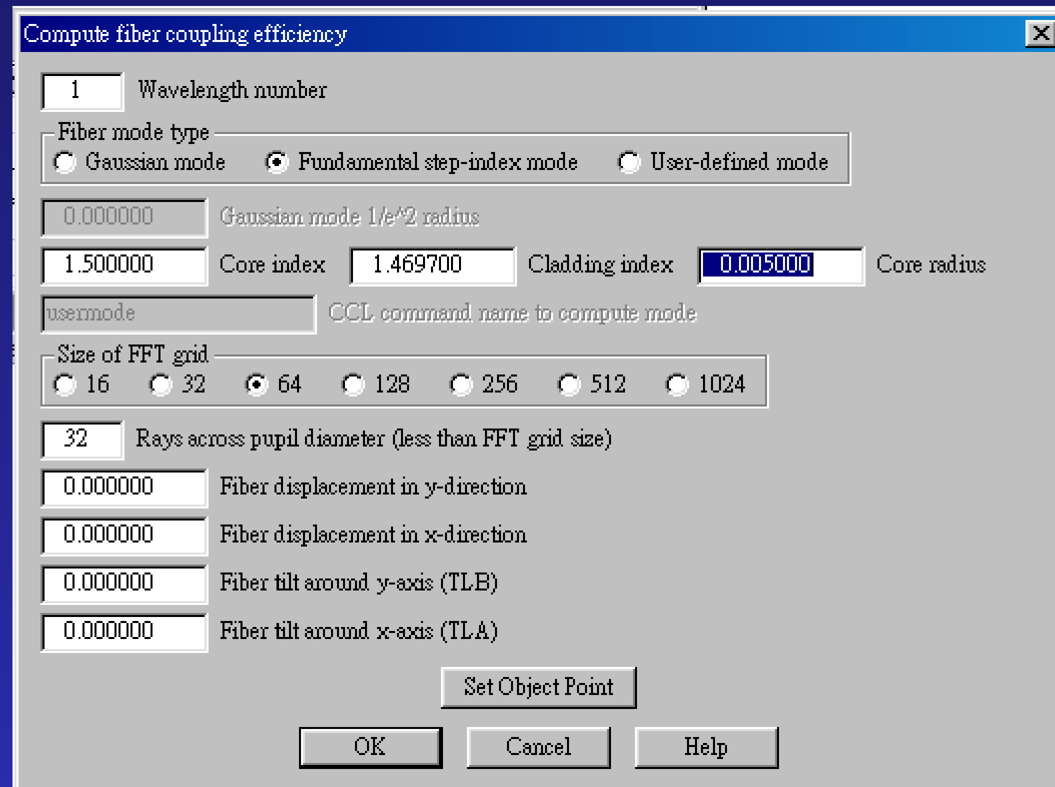
Fiber coupling efficiency calculation

- Computation of coupling efficiency is one of the applications of point spread function.
- Coupling efficiency :

$$\eta = \frac{\iint U(x',y')\Psi'(x',y')dx'dy'}{\sqrt{\iint U(x',y')U^*(x',y')dx'dy'\iint \Psi(x',y')\Psi^*(x',y')dx'dy'}}$$

  - U(x,y) : amplitude diffraction function
  - Ψ(x,y) : fiber mode pattern

Fiber coupling efficiency calculation




```
*FIBER COUPLING EFFICIENCY - WAVELENGTH 1
 FUNDAMENTAL MODE OF STEP-INDEX FIBER
 CORE INDEX =     1.500000 CLADDING INDEX =     1.469700 CORE RADIUS =     0.005000
 FIBER DISPLACEMENT    Y        --         X        --
 FIBER TILT           TLB       --        TLA       --
 POWER COUPLING =     0.000361       ( -34.42      dB)
 AMPLITUDE COUPLING     REAL =    -0.0189     IMAGINARY =     0.002009
```

References

- “OLSO optical reference”
- “Modern optical engineering”, Warren J. Smith
- “Lens design”, Milton Laikin
- “Achromatic polarization-preserving beam displacer,” E. J. Galvez, Opt. Lett. Vol. 26, pp. 971-973 (2001) for example 2.
- “Astigmatic light source in optical design software,” S. Thibault, Opt. Eng. Vol.39, pp. 1808-1811 (2000) for example 3.