Essential Topics in Optics 1.4

Concepts for comprehension

And

Mathematics for application

Course Description

- Morning Session
  - Emission
  - Electromagnetic waves
  - Refractive index
  - Reflection & Transmission
  - Fourier optics
  - Paraxial optics
  - Contrast
- Afternoon Session
  - Detectors
  - Noise
  - Filters
  - Aberration
  - Resolution
  - Depth-of-focus
  - Glass materials
  - ISO specification

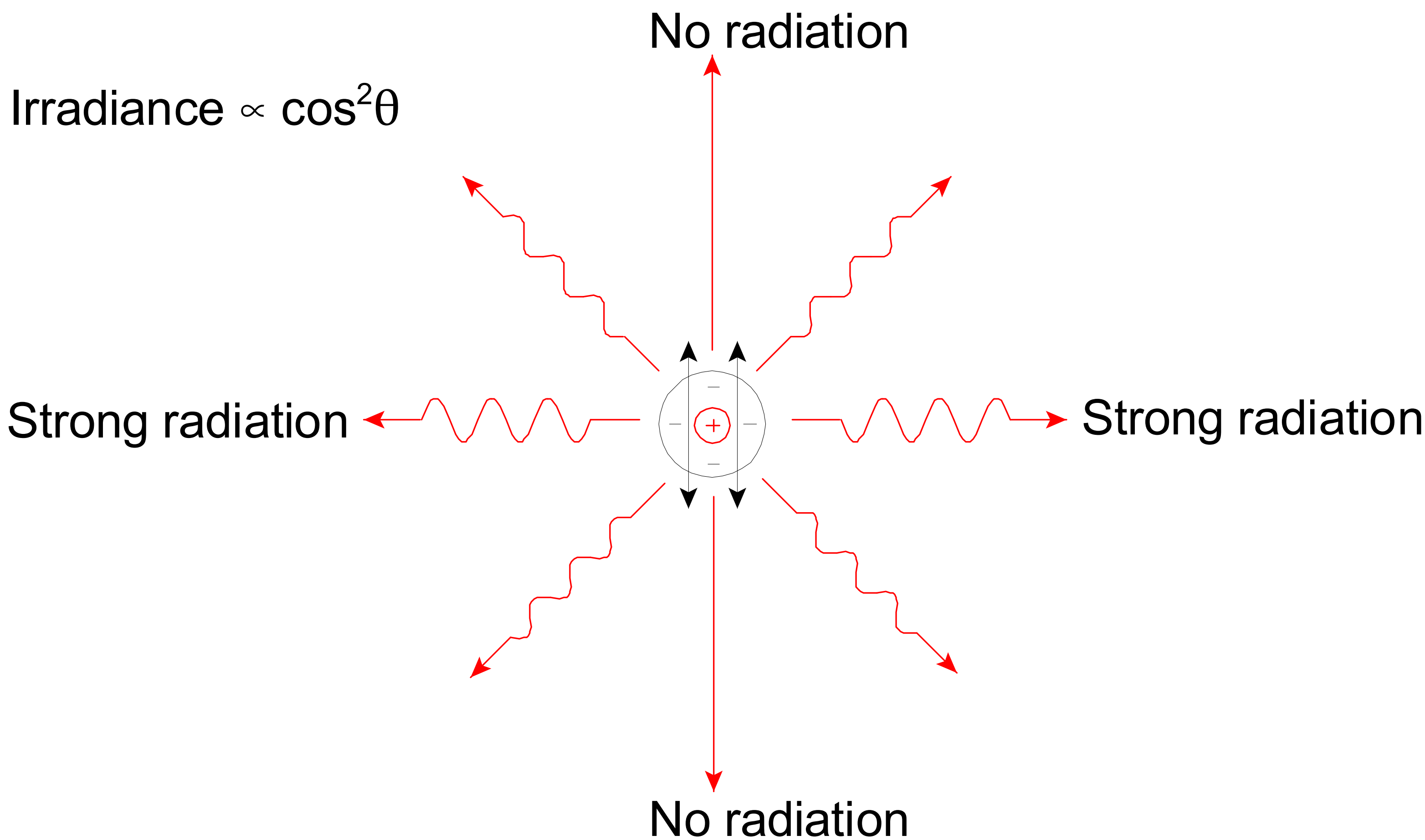
Learning Outcomes

After completion of this course the students may…

- Appreciate the complexity of optical design
- Comprehend formulae of optical design
- Identify important optical issues
- Specify metrics for an optical instrument

Dipole current creates EM Wave

Irradiance $\propto \cos^2\theta$



Mathematical Expression of Wave

- An EM wave requires acceleration of charge
- Current density J, is product of
  - Charge density, ρ
  - Velocity, x-dot
- Acceleration of current density, J-dot, is product of
  - Charge density, ρ
  - Acceleration of charge, x-double-dot
- Spatial curvature of electric field, del-squared E, depends upon
  - Temporal curvature of E, double-dot E
  - Acceleration of current density, J-dot

$$\mathbf{J} = \rho\,\dot{\mathbf{x}}$$

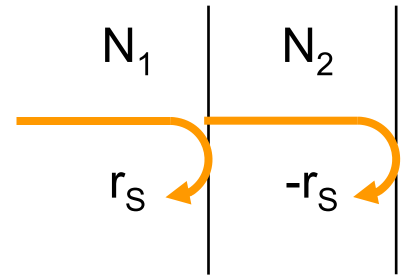
$$\dot{\mathbf{J}} = \rho\,\ddot{\mathbf{x}}$$

$$\nabla^2\mathbf{E} = \mu\left(\varepsilon_0\ddot{\mathbf{E}} + \dot{\mathbf{J}}\right)$$

Reflectance approximations

- Reflection coefficients at normal
  - Flip polarity with polarization
  - Flip polarity with direction
- As thin film thickness approaches zero
  - Summation of equal but opposite occurs
  - Yields zero reflection coefficient
  - True for all angles
- Reflectance R
  - Same for both polarizations
  - Same for both directions
  - Valid up to Brewster window

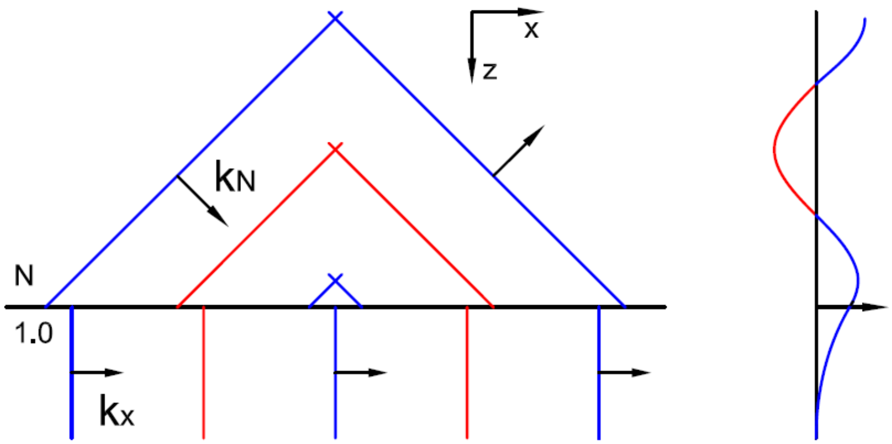
$$r_{SN} = -r_{PN} = \frac{N_1 - N_2}{N_1 + N_2}$$



$$R = |r|^2 = \left(\frac{N_1 - N_2}{N_1 + N_2} \right)^2$$

$$\tan(\theta_B) = \frac{N_2}{N_1}$$

Evanescent field



$$2\mathbf{E}_0 \cos(k_x x - \omega t)\cos(k_z z - \phi_N)$$

$$\mathbf{E}_0 \cos(k_x x - \omega t)\exp(-\alpha_z z - \phi_0)$$

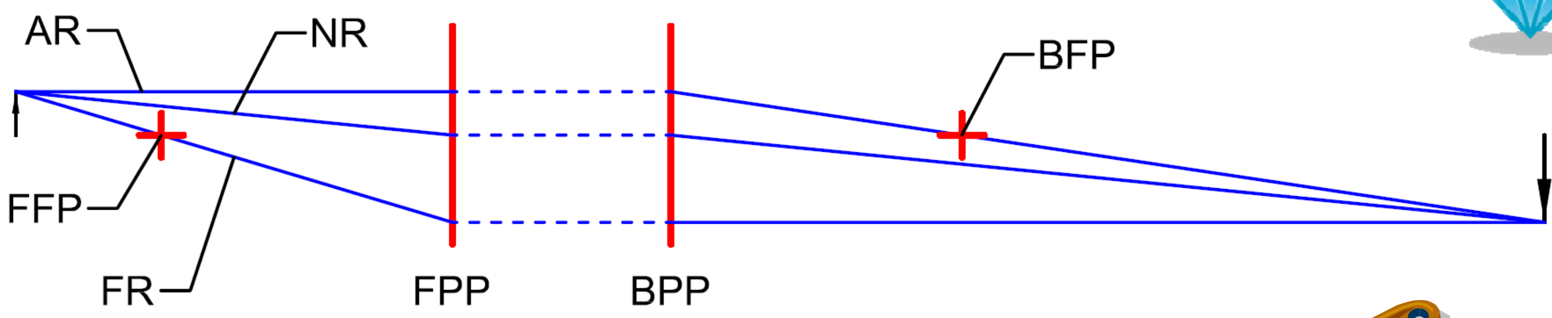
$$k_N = N\frac{\omega}{c}$$

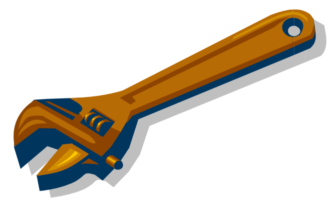
$$k_x = k_N \sin\theta \geq \frac{\omega}{c} = k_0$$

$$k_x^2 - \alpha_z^2 = k_N^2$$

- Ordinary spatial frequency k_N
  - temporal frequency ω
  - Refractive index N = n + iκ
- Extraordinary spatial frequency $k_x > k_0$
- Creates evanescent decay $\alpha_z > 0$

Thick lens separates PP

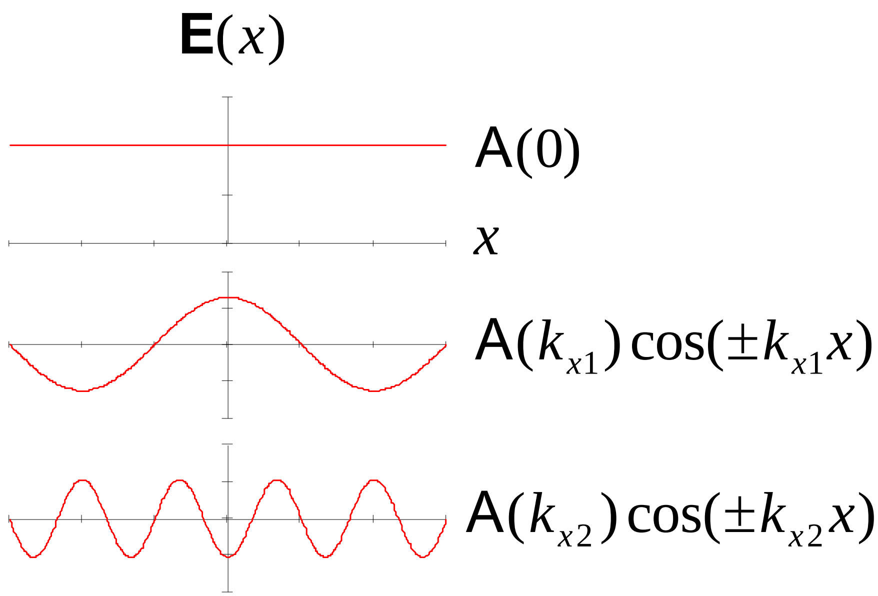


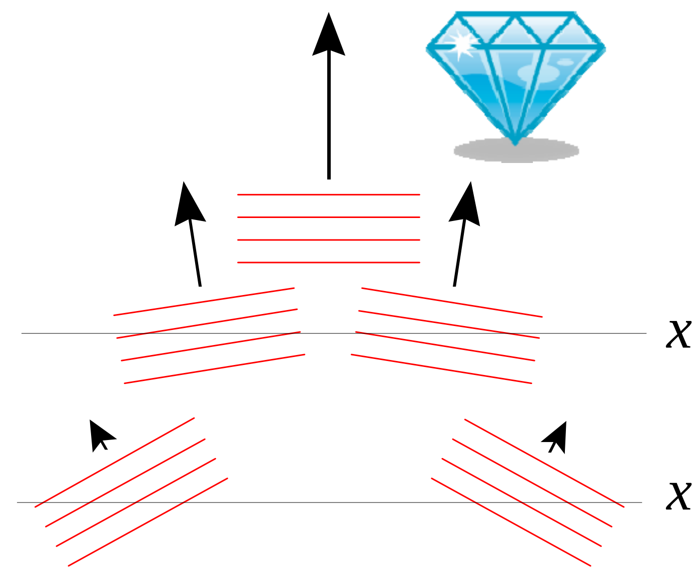


- Principle planes
  - Front principle plane FPP
  - Back principle plane BPP
  - Transformation between planes at right

$$\begin{vmatrix} y' \\ m' \end{vmatrix} = \begin{vmatrix} 1 & 0 \\ -1/f & 1 \end{vmatrix} \cdot \begin{vmatrix} y \\ m \end{vmatrix}$$

Angular distribution of plane waves





- Different k_x waves are summed

$$\int A(k_x)\exp(ik_x x)dk_x$$

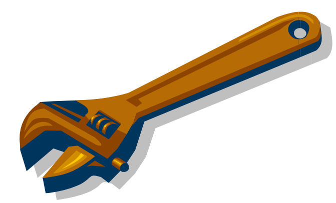
- same k at different directions θ

$$k_x = \mathbf{k}\cdot\hat{\mathbf{x}} = k\cos\theta$$

Space-angle product of waves

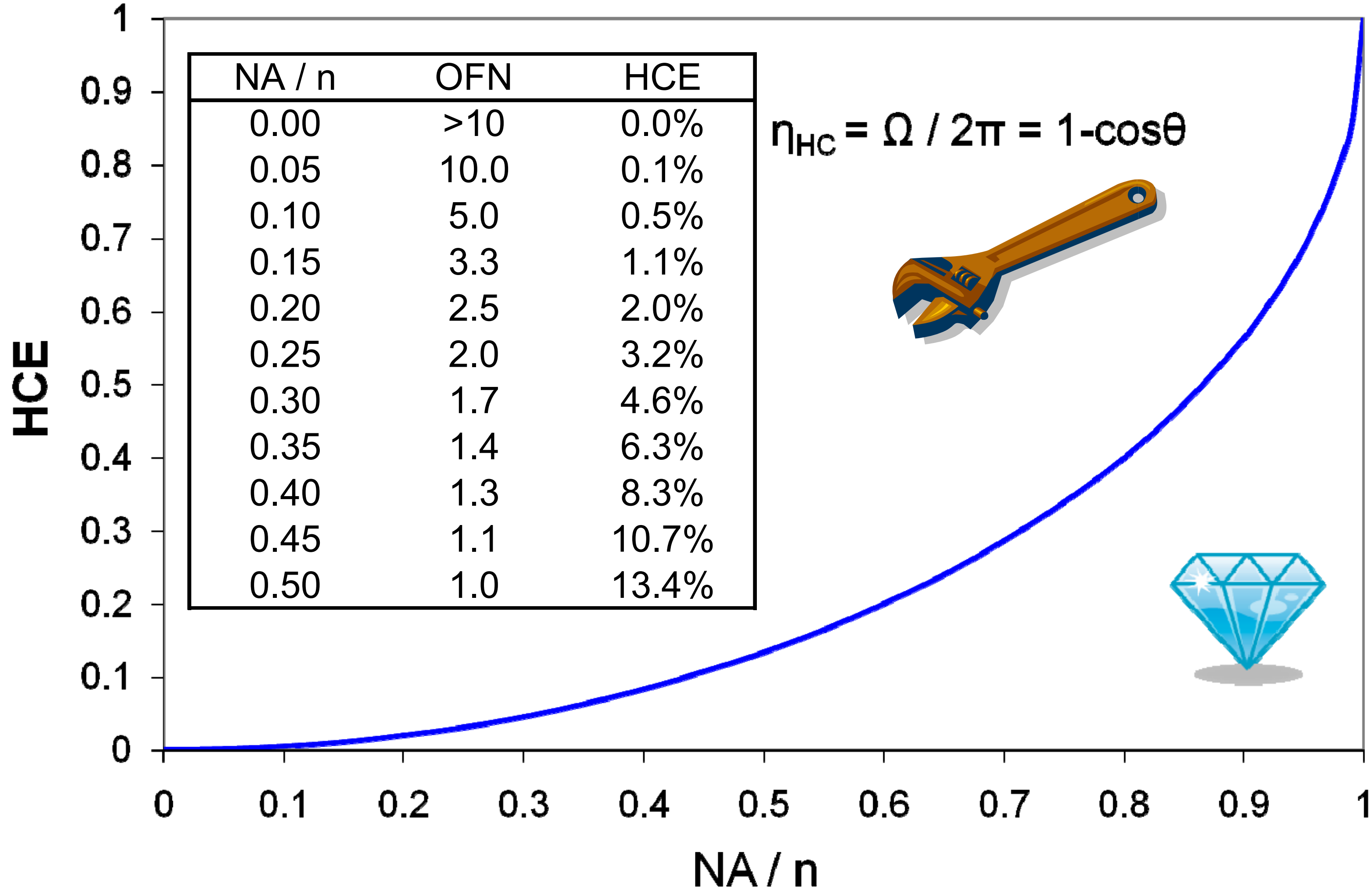
$$A\Omega \geq \lambda^2$$

Cannot be made smaller
without
creation of evanescent field



$$A_0\Omega_0 = A_1\Omega_1 = \cdots = A_n\Omega_n \geq \lambda^2$$

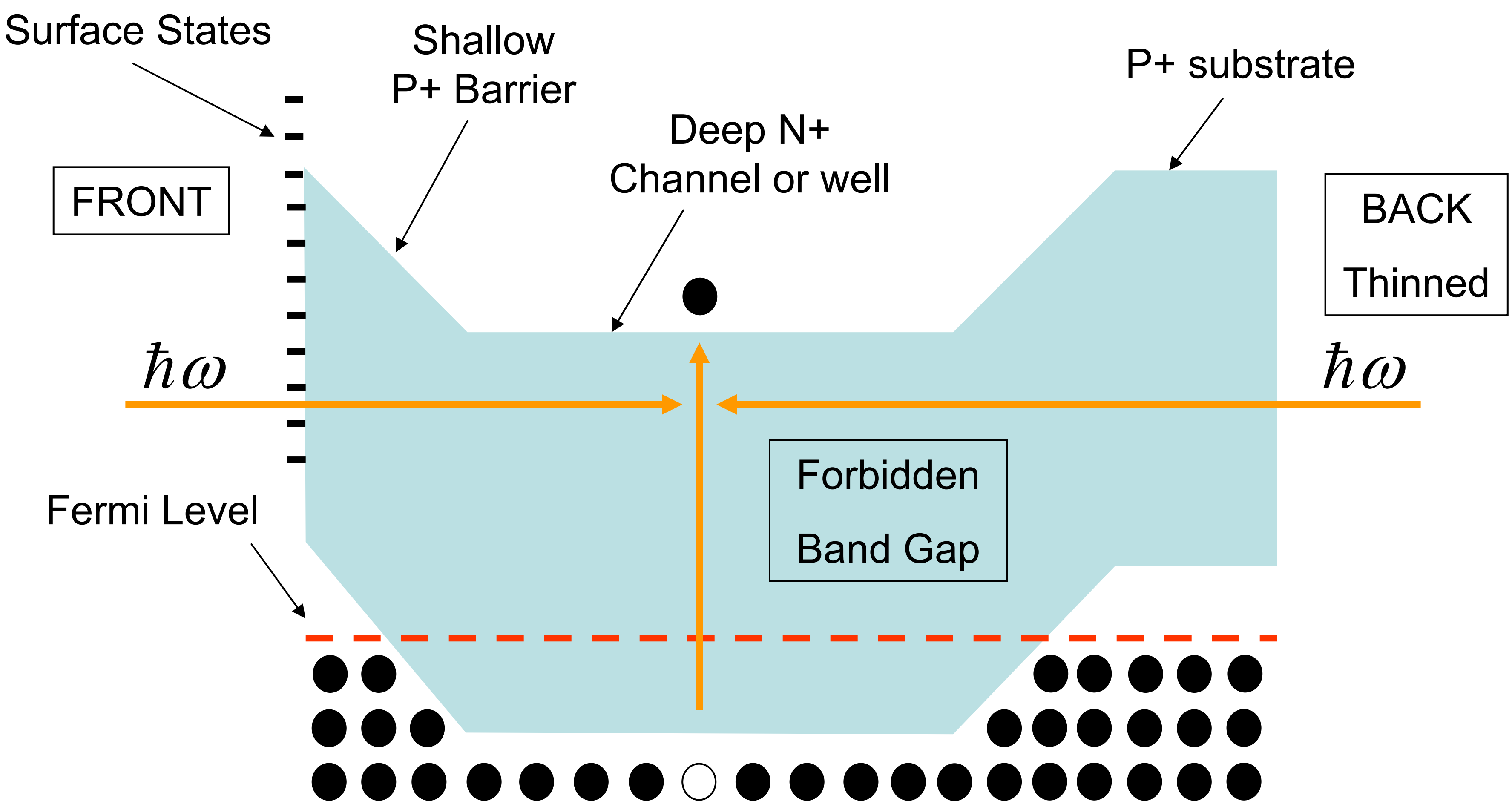
Hemispherical Collection Efficiency η_{HC}



NA / n	OFN	HCE
0.00	>10	0.0%
0.05	10.0	0.1%
0.10	5.0	0.5%
0.15	3.3	1.1%
0.20	2.5	2.0%
0.25	2.0	3.2%
0.30	1.7	4.6%
0.35	1.4	6.3%
0.40	1.3	8.3%
0.45	1.1	10.7%
0.50	1.0	13.4%

$$\eta_{HC} = \Omega / 2\pi = 1-\cos\theta$$

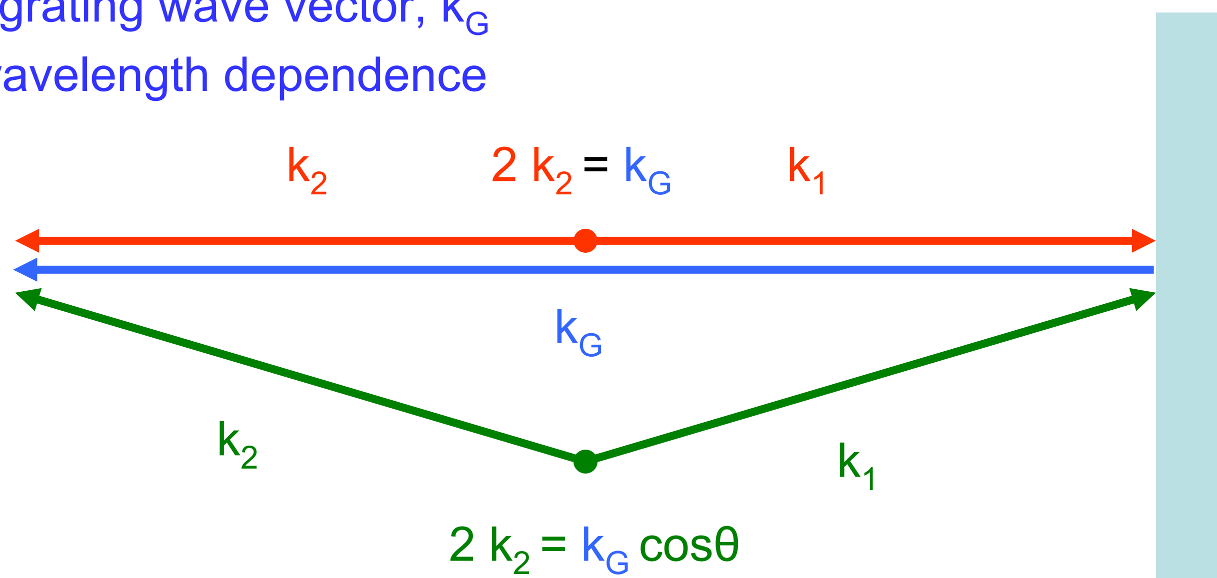
Buried Channel & Deep Well



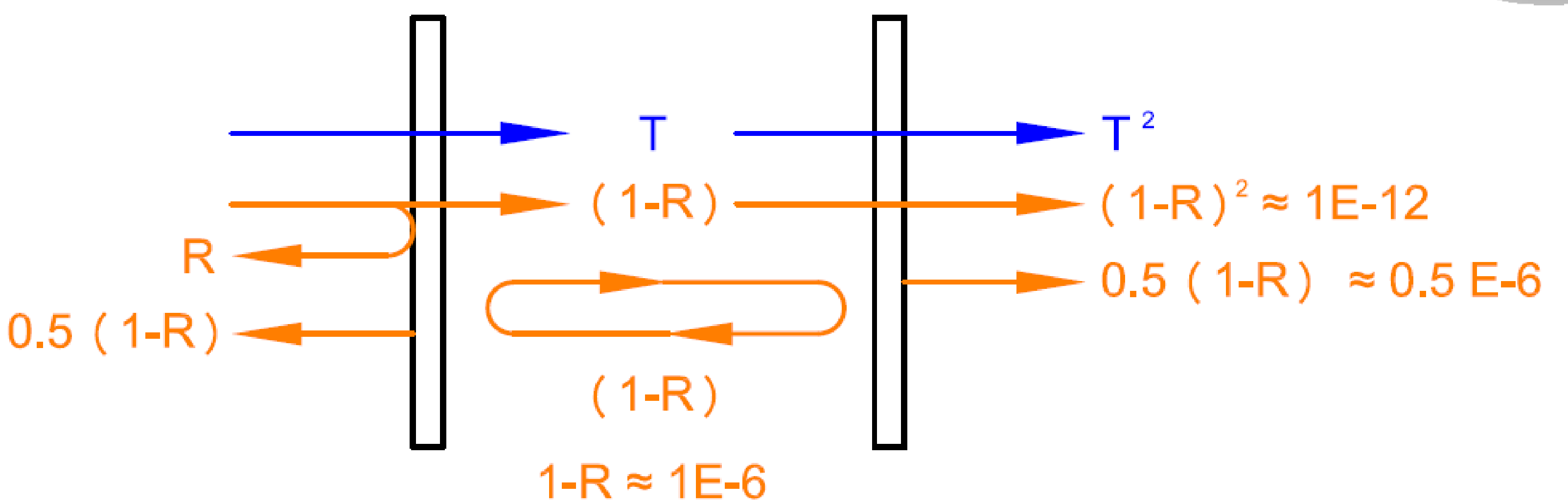
Holographic filters

- planar sinusoidal index profile
  - Creates grating vector k_G
- Exit wave vector, k_2 equals
  - incident wave vector, k_1
  - plus grating wave vector, k_G
- Strong wavelength dependence

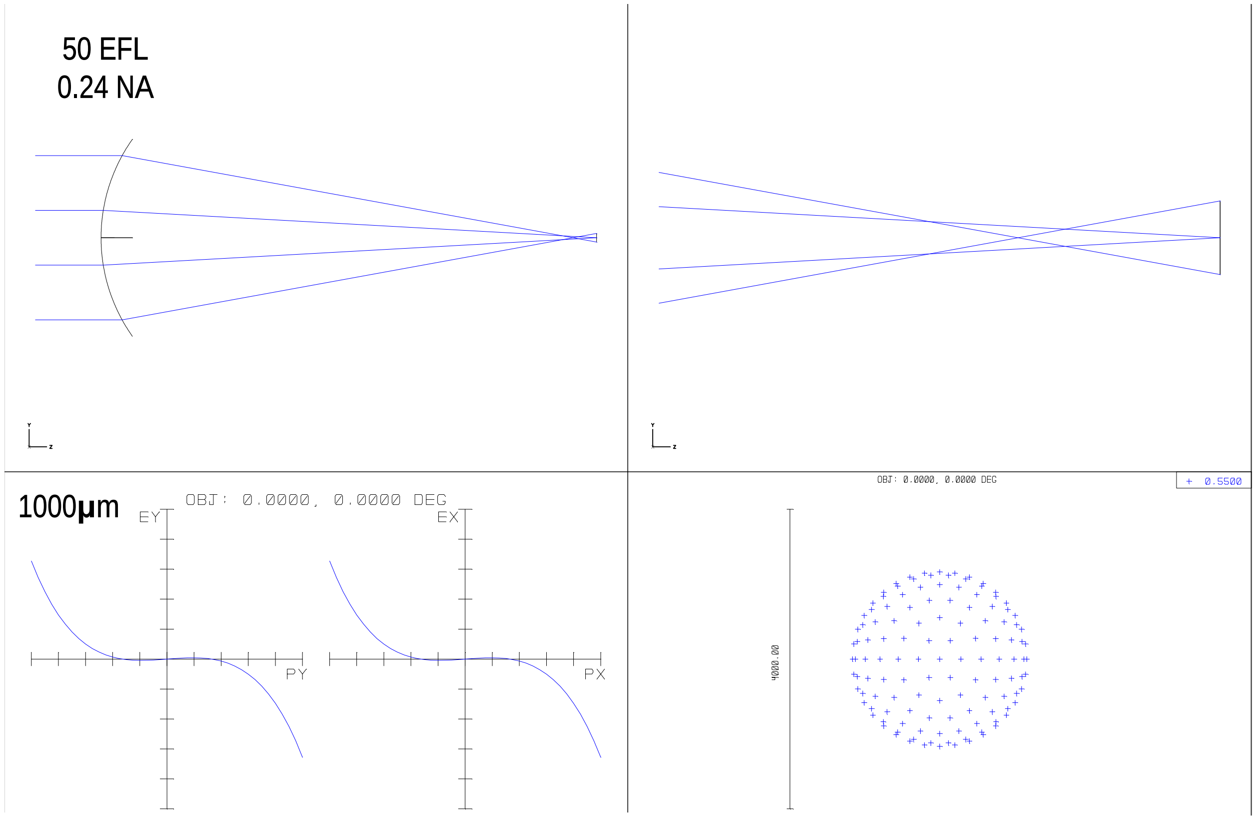
$$\mathbf{k}_2 = \mathbf{k}_1 + \mathbf{k}_G$$



Filter doublet



Spherical aberration



- Cubic dependency P^3
  - Error E upon pupil location P
- Due to spherical shape
- Marginal rays
  - Bend too much
  - Focus early

Periodic Table for optical glass

soda lime

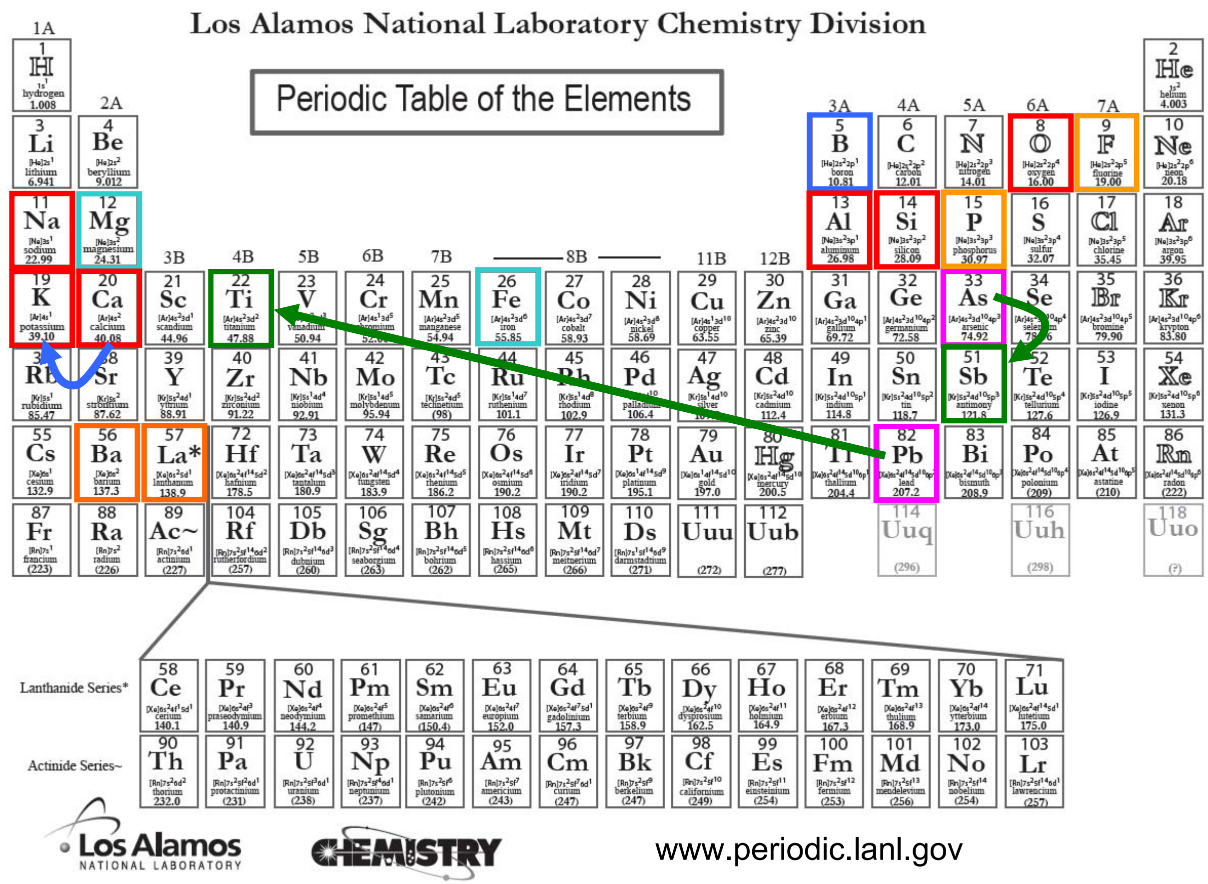
borosilicate

lead crystal

low dispersion

Environmentally Safe

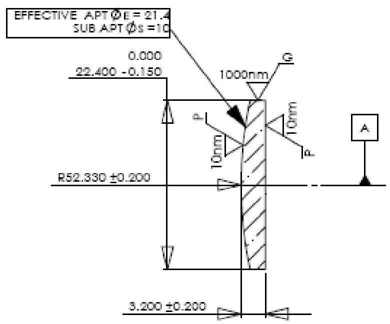
Trace elements



Fabrication drawing

Versions

Version	DESCRIPTION	DATE	APPROVED
1	INITIAL DESIGN	11/26/2007	G SEWARD L KIM



LEFT SURFACE	MATERIAL	RIGHT SURFACE
R 52.330 convex	N-BK7	R Plano
λ 1% R 400-650nm	Nd = 1.517 ± 0.1%	λ 1% R 400-650nm
3/ 2; (0.3/-) 565nm in ∅S	Vd = 64.17 ± 0.1%	3/ 2; (0.3/-) 565nmin ∅S
4/ -;0.05	0/ 10	4/ -;-
5/ 5x0.06L; 5x0.40D in ∅S	1/ 5x0.40 in ∅S	5/ 5x0.06L; 5x0.40D in ∅S
6/ E; WL; PD; F; NSxNP	2/ 1,4 in ∅S	6/ E; WL; PD; F; NSxNP
NOTES:	NOTES:	NOTES:

	CATEGORIES ISO10110	UNITS	
REFERENCE MATERIAL SOLE PROPERTY OF L-A-OMEGA. MODEL OPTICS IS GRANTED UNLIMITED USE OF THE DESIGN.	0/ stress birefringence (phase per glass)	nm/cm	CLIENT MODEL OPTICS WOODSTOCK, NY (845) 679-7386
	1/ bubbles and inclusions (N x size)	mm	
	2/ inhomogeneity and striae	class	DESIGNER LAOMEGA.COM
This drawing might contain CONFIDENTIAL information. It should not be viewed without permission from either L-A-OMEGA or CLIENT.	3/ surface form error (power; irreg/sagittal)	fringes	TITLE PCX100 Lens
	4/ centering error (tilt ; decenter)	arcmin; mm	
	5/ surface imperfections (N x size) Scratch, Dig, Coating, Edge	mm	SIZE A DWG. NO. ISO - 1 VER. 1
	6/ laser damage threshold (Exposure; λ; PulseDuration; Frequency; N sites; N pulses)	J/cm2 or W/cm2	SCALE 1:5 SHEET 1 OF 2

2/ INHOMOGENEITY	
CLASS	ISO CAT 2
5	±0.5E-6
4	±1E-6
3	±2E-6
2	±5E-6
1	±20E-6
0	±50E-6

2/ STRIAE CLASSIFICATION			
MIL-G-174		ISO CAT 2	
GRADE	STRIAE (shadow test)		STRIAE (<30nm WFE)
A	INVISIBLE	5	extremely free as noted
B	BARELY VISIBLE	4	<1% ∅s
C	BARELY VISIBLE AND PARALLEL TO FACE	3	<2% ∅s
D	VISIBLE AND PARALLEL TO FACE	2	<5% ∅s
		1	<10% ∅s

0/ STRESS BIREFRINGENCE	
APPLICATION	PHASE PER GLASS (nm / cm)
INTERFEROMETRY	<2
TELESCOPES	5
MICROSCOPES	10
ILLUMINATION	1

ASPHERIC SURFACE

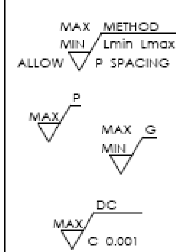
$$z = R\frac{(y/R)^2}{1+\sqrt{1-(1+\kappa)(y/R)^2}} + \sum A_n r^n$$

κ CONIC CONSTANT

An POLYNOMIAL COEFFICIENT

5/ SURFACE IMPERFECTIONS			
ANSI		ISO CATEGORY 5	
SCRATCH	DIG	SCRATCH	DIG
80	50	5x0.08L	5x0.50
60	40	5x0.06L	5x0.40
40	20	5x0.04L	5x0.20
20	10	5x0.02L	5x0.10
10	5	5x0.01L	5x0.05

SURFACE TEXTURE



MAX	RMS ROUGHNES MAXIMUM DEPTH	µm
MIN	RMS ROUGHNES MINIMUM DEPTH	µm
ALLOW	ALLOWANCE FOR REMOVAL	µm
METHOD	P - POLISH G - GRIND E - ETCH SB- SANDBLAST DC - DIAMOND CUT	
Lmin	SAMPLING LENGTH MINIMUM	mm
Lmax	SAMPLING LENGTH MINIMUM	mm
SPACING	SPACING OF PATTERN C - CIRCULAR X - CROSSED II - PARALLEL P -PARTICULATE	mm

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	4/ centering error (tilt ; decenter)	arcmin; mm	
	5/ surface imperfections (N x size) Scratch, Dig, Coating, Edge	mm	SIZE A DWG. NO. ISO - 1 VER. 1
	6/ laser damage threshold	J/cm2 or W/cm2	SCALE 1:5 SHEET 2 OF 2