- Technical
- Social
- Political
- Economic

- Problem Definition
- Figure of Merit
- System Design
- Constraints, Tradeoffs
- Statistics of Variation
- Tolerance, Capability

3.003 Principles of Engineering Practice

Research Methodology (10min)

The Ethical Engineer (30min)

Light-Matter Interactions (10min)

Lionel C. Kimerling

Laboratory Methodology

The Complete Engineer's Skill Set
Technical—Social—Political--Economic

- Problem Definition
- Constraints
- Options
- Analysis
- Solution

3.003 Technology Problems

The Complete Engineer's Skill Set

Technical—Social—Political--Economic

Add the following to your lab report.

- Problem Definition
  - What problem is the team solving?
- Experiment Design
  - What are the constraints that the team faces?
- Solution
  - Justify the experimental design?

3.003 Technology Problems

The Complete Engineer's Skill Set
Technical—Social—Political--Economic

- Problem Definition
  - Attributes, Specifications
- *Design*
  - Constraints
    - Figure of Merit: Tradeoffs
  - Options
  - Analysis
    - Statistics of Variation: Tolerance, Capability
- Solution
  - Results

Figure of Merit

Materials Design

Property relation to Performance

- Example: problem and constraint
  - *load bearing with lightest weight*
- Volume = LxA
- P = load

$(1/m)_{max}$ = Performance

Materials Properties

- tensile strength = σ = P/A=load/area
- m = density x volume = ρAL

$1/m = \sigma/\rho \times 1/PL$

FOM =1/m= σ/ρ =tensile strength/density

Ethical Practice

An Ethical Engineer?

- Conflicting motivations
  - divergence between commerce and engineering?
  - is the data sufficient?
- Ethical action
  - most good for most people?
  - absolute right and wrong?
- Dealing at the boundaries

Laboratory Methodology

The Complete Engineer's Skill Set
Technical—Social—Political--Economic

- Problem Definition
- Constraints
- Options
- Analysis
- Solution

Ethics Basics

- Absolute of Judgment?
- Rationale: good world or self?
- Truth = 'fuel of the mind'
  - *science of variation*
- Can sustainability be built on fiction?
  - Ethics is not an act, but a lifetime; it is the definition of self

The Puzzle of Moral Judgment

- Kant
  - Right is principles that everyone can follow.
- Mill
  - Right is the greatest good for the greatest number of people.

Right before good or good before right?

Ethics: Private vs. Public

- Your purpose in life
- Your methods of achieving that purpose

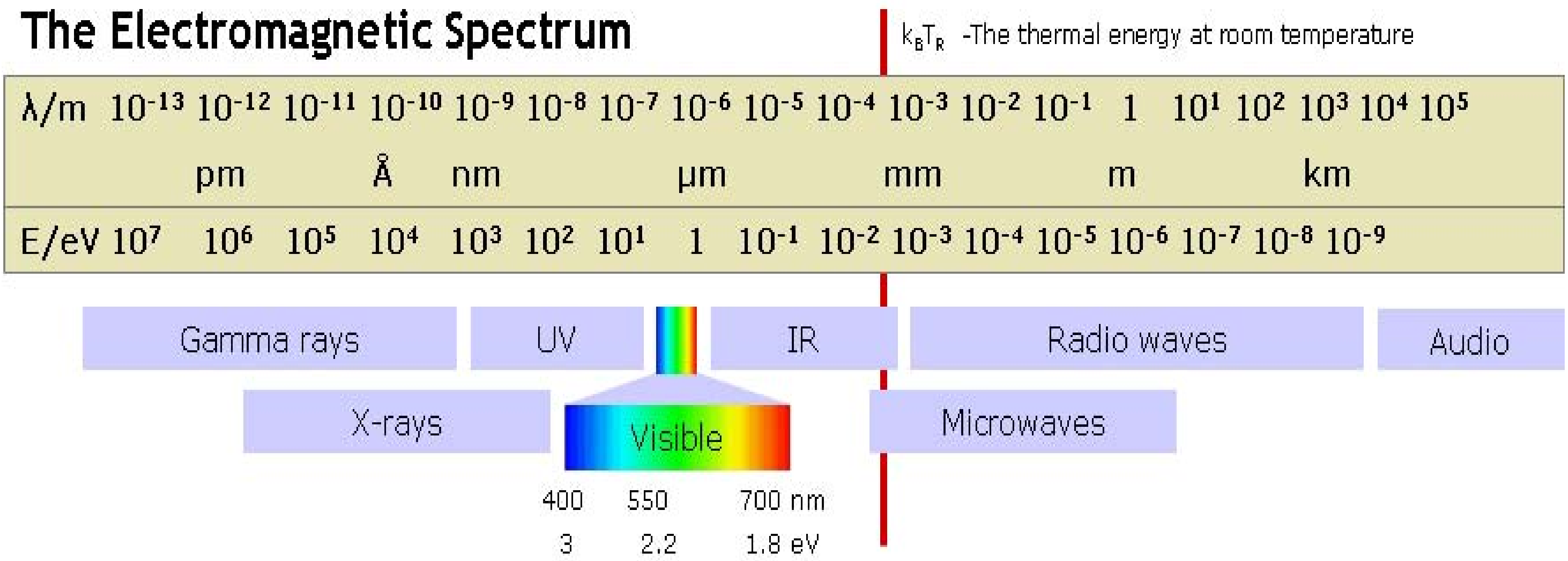
Ethics: Private vs. Public

HYPOTHESIS OR FACT?

- The way that you live has consequences for the lives of others.

Light and Matter

Light is an Electromagnetic Wave



Courtesy of the Opensource Handbook of Nanoscience and Nanotechnology.

Observables

Electromagnetic Field

- voltage $\vec{E}(\vec{r},t)$
- current $\vec{H}(\vec{r},t)$

Photonic Materials

- dielectric constant, $\varepsilon/\varepsilon_0$
- index of refraction, n
- absorption, α

- wavelength, λ
- group velocity, $v_g = c_o/N$; N = group index
- power, P

$c_{material} = c_0/n_r \quad n_r = (\varepsilon/\varepsilon_0)^{1/2}$

	$\frac{\varepsilon}{\varepsilon_0}$ (static)	n (υ)
Si	11.7	3.5
Ge	16	4
$LiNbO_3$	43	2.27
$BaTiO_3$	3600	2.46

c=speed of light; n_r=refractive index; ε= electric permittivity $\varepsilon/\varepsilon_0$=dielectric constant

Materials Design by Property Maps

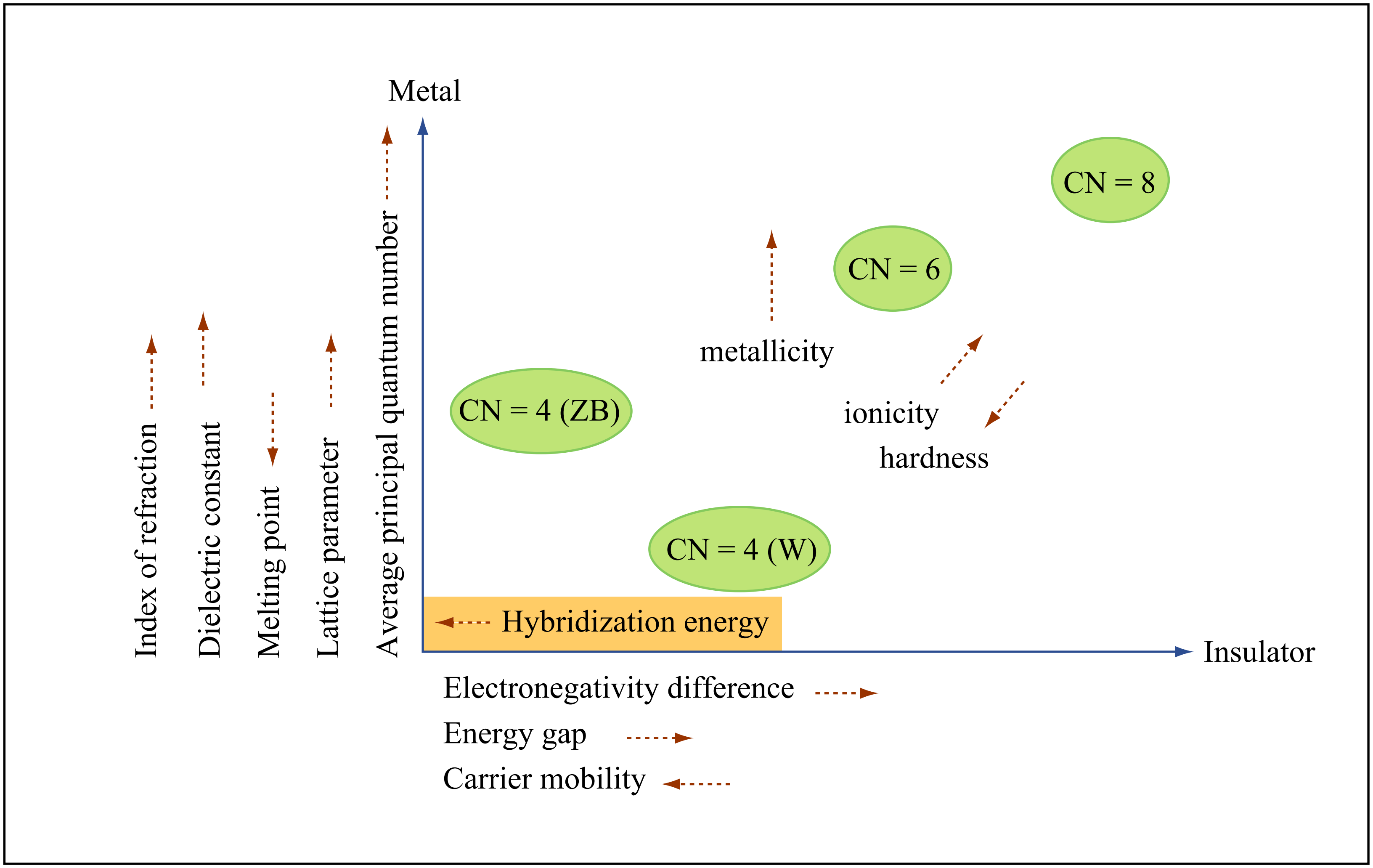
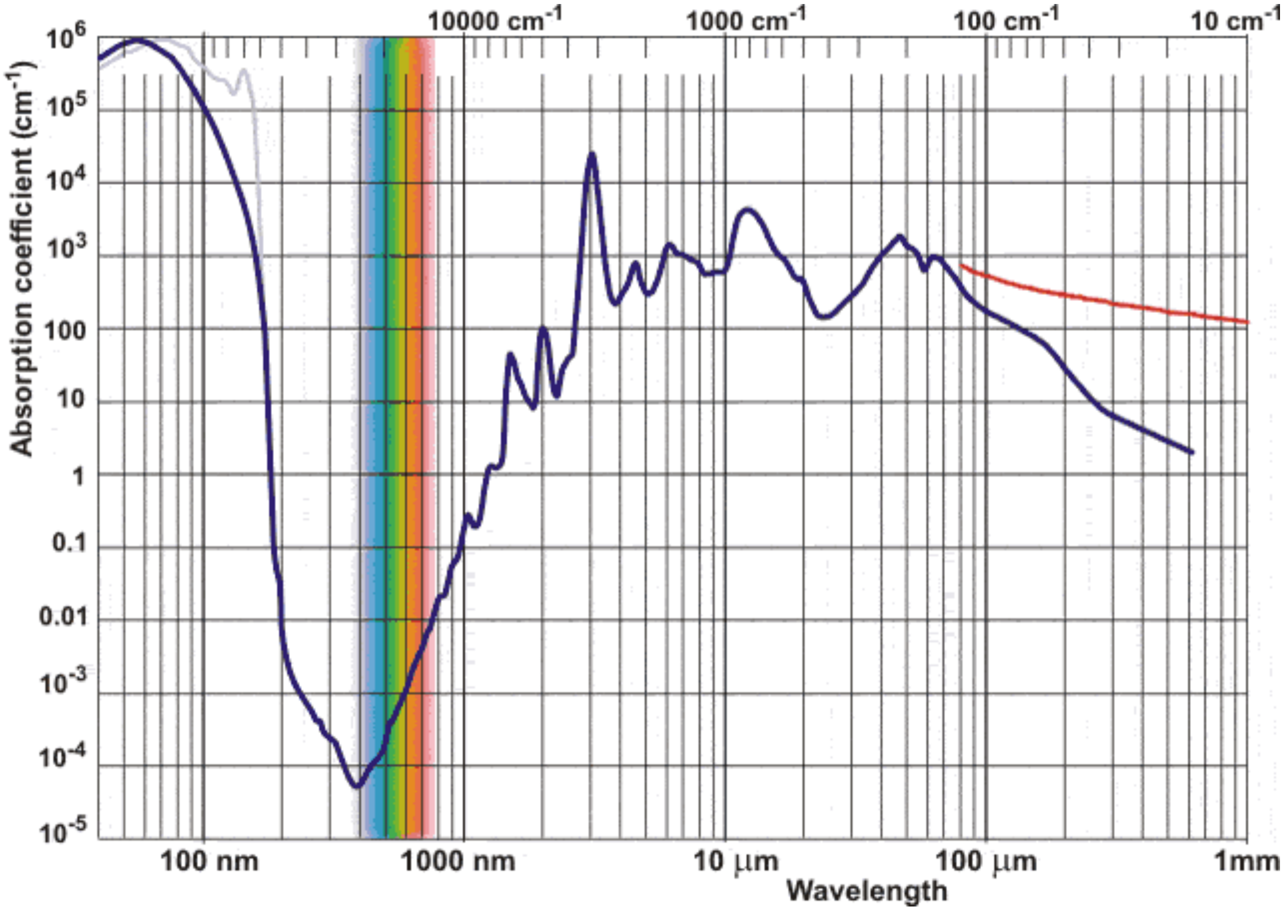


Figure by MIT OpenCourseWare.

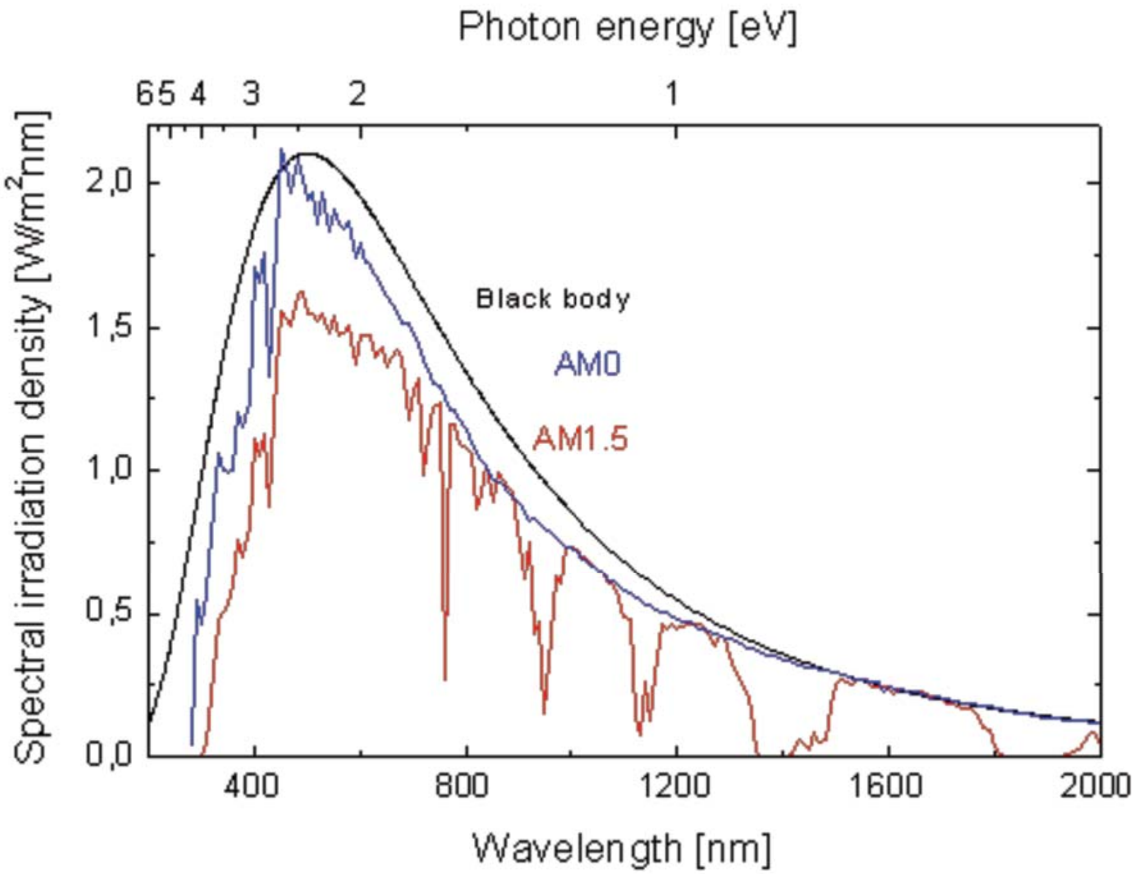
Lab #1 Appendix 1
Water Vapor and AR Coatings

Optical absorption of water



Courtesy of Martin Chaplin. Used with permission.

Solar spectrum



From Haug, Franz-Josef. "Irradiation Spectrum." *Solar Cells: Generating Electricity from Light*. Used with permission.

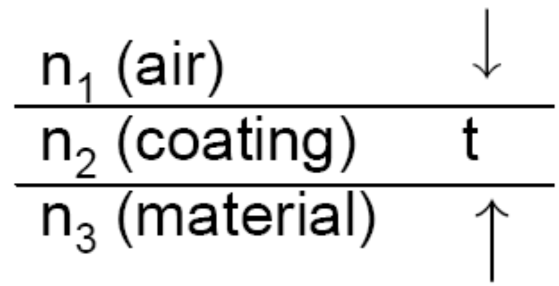
Refractive indices

Material	*Refractive index*
Air	1.0
Water	1.33
SiO_2	1.5
Si_3N_4	2.0
Si	3.5

Anti-reflection (AR) coatings

Elimination of reflection on surfaces:

- ✓ Solar cells
- ✓ Photodetectors
- ✓ Photolithography



$$R = \frac{n_2^2 - n_1 n_3}{n_2^2 + n_1 n_3}$$

$$= 0 \quad \text{when} \quad n_2 = \sqrt{n_1 n_3}$$

$$t = \frac{\lambda_0}{4 n_2}$$

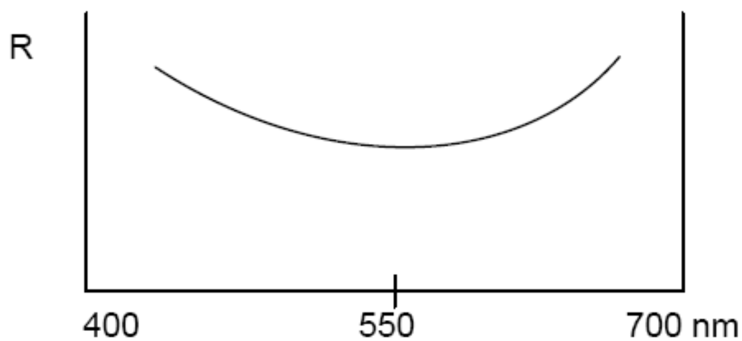
Quarter wave film

Example: AR coating for silicon

$n_{Si} = 3.5 \quad n_{AR} = 2.3$

$n_{SiO2} = 1.51$

$\lambda = 550$ nm $\rightarrow t = 91$ nm



SiO_2-on-Si Color Chart

Film thickness, microns	Color and comment	Film thickness, microns	Color and comment
0.05	Tan	0.68	"Bluish"
0.07	Brown	0.72	Blue-green to green (quite broad)
0.10	Dark violet to red-violet	0.77	"Yellowish"
0.12	Royal blue	0.80	Orange (rather broad for orange)
0.15	Light blue to metallic blue	0.82	Salmon
0.17	Metallic to very light yellow-green	0.85	Dull, light red-violet
0.20	Light gold to yellow - slightly metallic	0.86	Violet
0.22	Gold with slight yellow-orange	0.87	Blue-violet
0.25	Orange to melon	0.89	Blue
0.27	Red-violet	0.92	Blue-green
0.30	Blue to violet-blue	0.95	Dull yellow-green
0.31	Blue	0.97	Yellow to "yellowish"
0.32	Blue to blue green	0.99	Orange
0.34	Light green	1.00	Carnation pink
0.35	Green to yellow-green	1.02	Violet-red
0.36	Yellow-green	1.05	Red-violet
0.37	Green-yellow	1.06	Violet
0.39	Yellow	1.07	Blue-violet
0.41	Light orange	1.10	Green
0.42	Carnation pink	1.11	Yellow-green
0.44	Violet-red	1.12	Green
0.46	Red-violet	1.18	Violet
0.47	Violet	1.19	Red-violet
0.48	Blue-violet	1.21	Violet-red
0.49	Blue	1.24	Carnation pink to salmon
0.50	Blue-green	1.25	Orange
0.52	Green (broad)	1.28	"Yellowish"
0.54	Yellow-green	1.32	Sky blue to green-blue
0.56	Green-yellow	1.40	Orange
0.57	Yellow to "yellowish"	1.45	Violet
0.58	Light-orange or yellow to pink borderline	1.46	Blue-violet
0.60	Carnation pink	1.50	Blue
0.63	Violet-red	1.54	Dull yellow-green

Figure by MIT OpenCourseWare.