Lasers and Photonics
EECS285B, Winter 2005

Professor & Class Schedule
Peter Burke
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Lect. M 6:00 – 8:50 pm
ELH 110

Optical communications course sequence

EECS 285A (W): Optical Communications
EECS 285B (W): Lasers and Photonics
EECS 285C (S): Integrated and Fiber Optics

Course description

UCI Catalog:

Covers the fundamentals of lasers and applications, including Gaussian beam propagation, interaction of optical radiation with matters, and concepts of optical gain and feedback. Applications are drawn from diverse fields of optical communication, signal processing, and material diagnosis. Prerequisite: undergraduate course work in electromagnetic theory and atomic physics.

My teaching philosophy:

1. You want to learn.

2. One of my jobs is to evaluate what you have learned (i.e. grade).

3. One of my jobs is to teach, with the aid of the textbook.

   Why bother coming to class?

   To ask questions! And, because I will tailor the class to your background. (Give background survey.)

Textbooks

Required:

J.T. Verdeyen, *Laser Electronics*, 3rd ed., Prentice Hall, 1995

Optional:

Yariv, "Optical Electronics and Modern Communications". 1997

B. E. A. Saleh and M. C. Teich, "Fundamentals of Photonics", 1991. A thorough treatment of lasers and classical optics.

Mandel and Wolf, "Optical Coherence and Quantum Optics", 1998. A very deep, excellent treatment of quantum optics.

Govind P. Agrawal, "Fiber-Optic Communication Systems", 1996. An overview from the systems point of view. Some detail on individual component operations.

Eberly, "Lasers", 1988, an excellent text on classical laser operation.

Riaziat, "Introduction to High-speed Electronics and Opto-electronics", 1996.

Course outline

Lecture 1: Introduction <36 pages
Lecture 2: Classical review of electromagnetic waves (Maxwell's equations) 49 pages
Lecture 3: Fields in a box 43 pages
Lecture 4: Planck, atomic physics, Einstein A/B coeffecients 55 pages
Lecture 5: Two level rate equations 38 pages
Lecture 6: Three level rate equations 21 pages
Lecture 7: Gain saturation, Fiber amplifiers 32 pages
Lecture 8: Laser oscillation 32 pages
Lecture 9: Laser output power 22 pages
Lecture 10: Time dependent oscillation 57 pages
Lecture 11: Example lasers 46 pages
Lecture 12: Band theory of solids 69 pages
Lecture 13: Optical properties of semiconductors 34 pages
Lecture 14: Semiconductor lasers 40 pages
Lecture 15: DBR, DFB semiconductor lasers 36 pages

Outline for today:

1. What is a laser?
2. How does it work?
3. What are some of the properties that I care about?
4. Reading for this lecture:
   Verdeyen chapter “0”

LASERS:

<u>L</u>ight <u>A</u>mplification by <u>S</u>timulated <u>E</u>mission of <u>R</u>adiation

Step 1: Build a "cavity":

LASERS:

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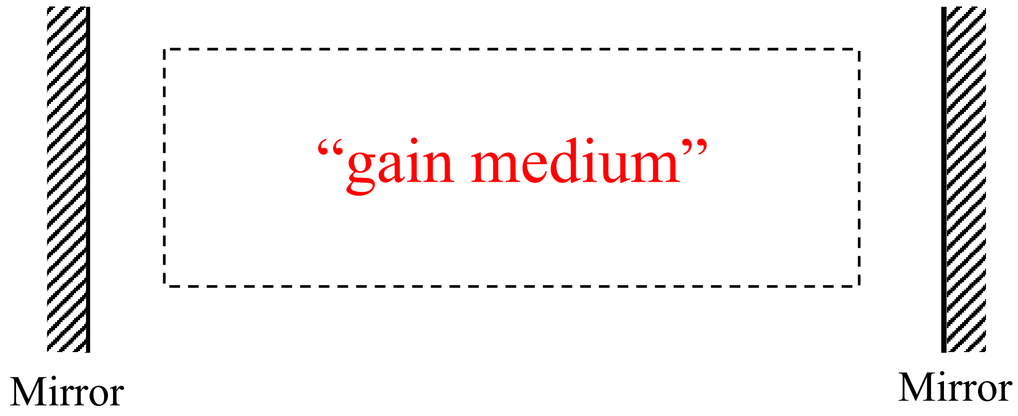
Step 1: Build a "cavity":

Step 2: Insert a "gain medium"

(special atoms in liquid, solid, or gas)



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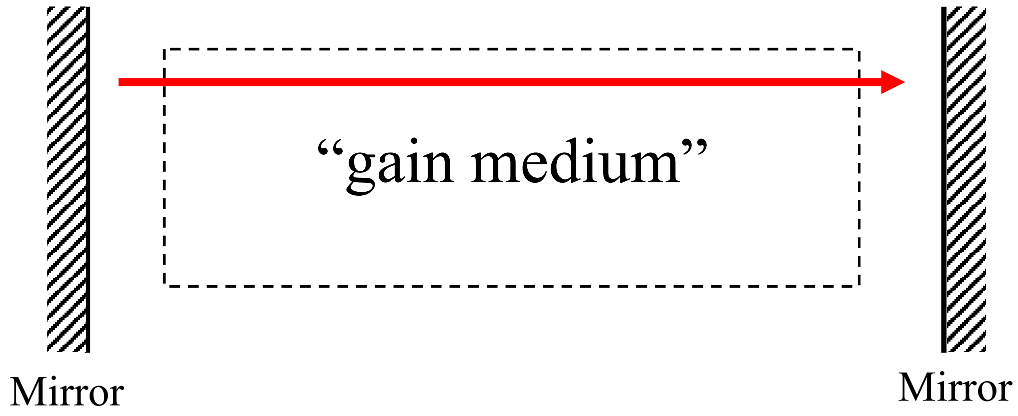
Step 1: Build a “cavity”:

Step 2: Insert a “gain medium”

Step 3: Start it up! (How?)



LASERS:

Light Amplification by Stimulated Emission of Radiation

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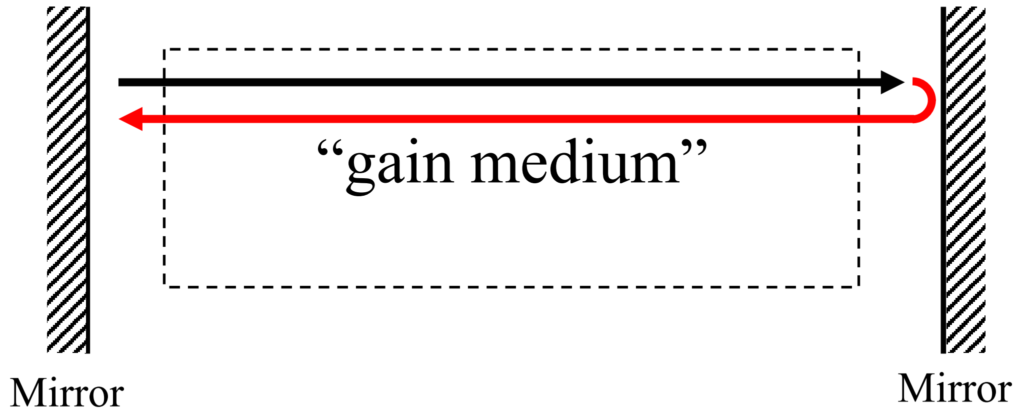
Step 2: Insert a "gain medium"

Step 3: Start it up! (How?)



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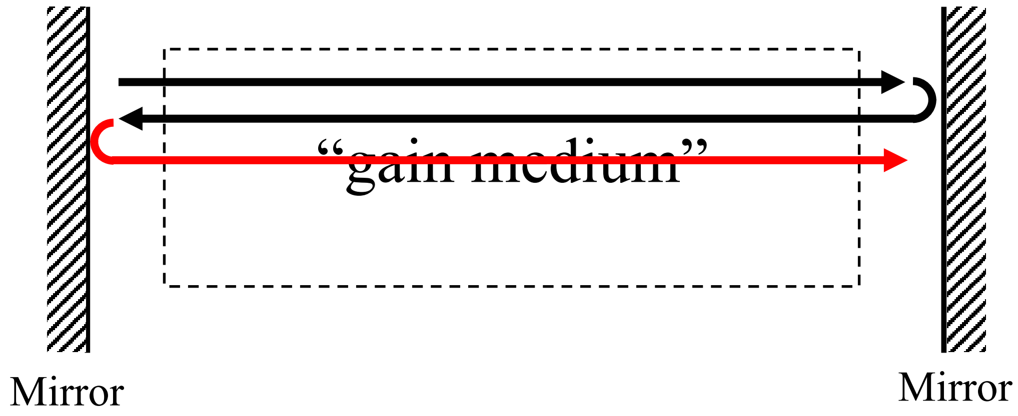

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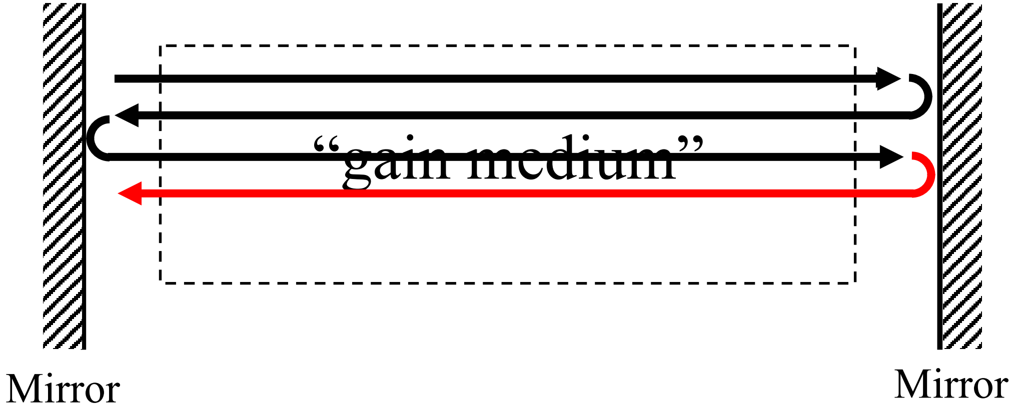

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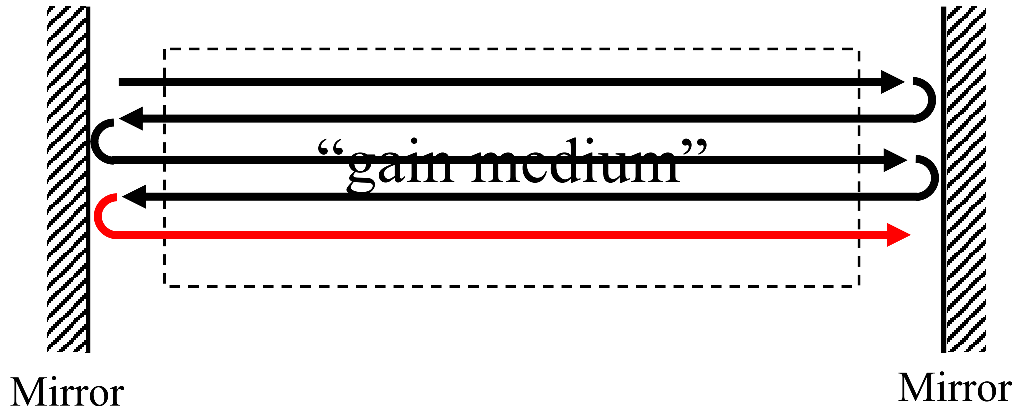

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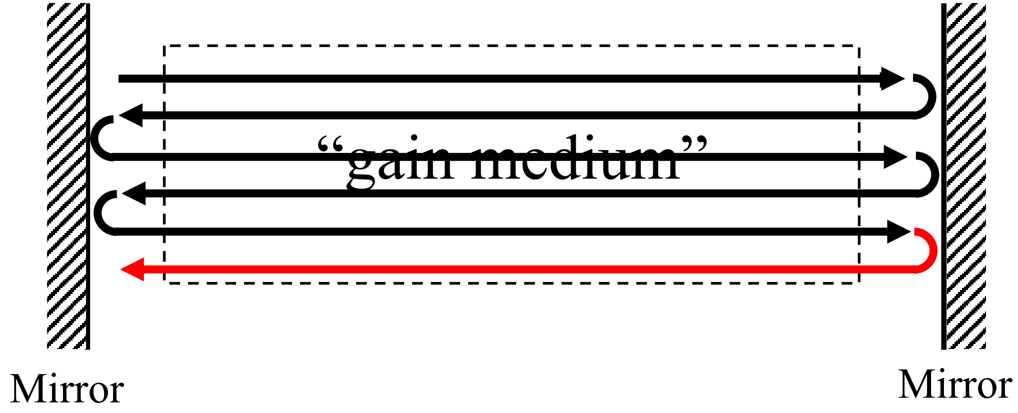

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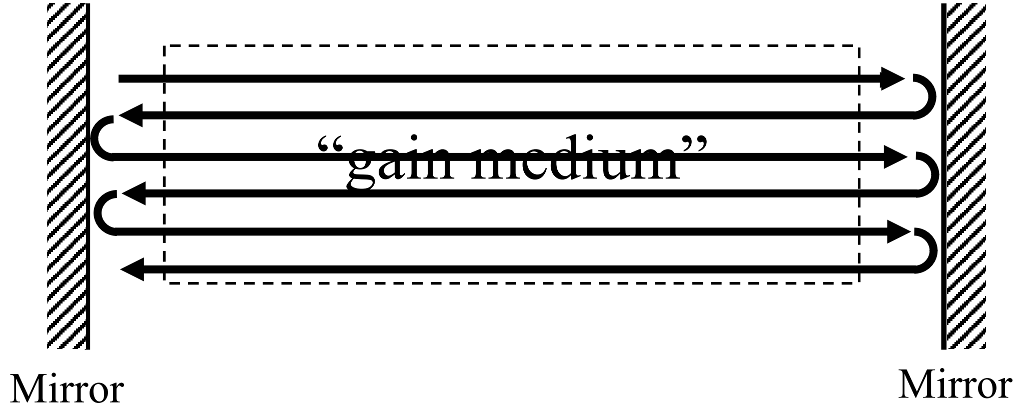
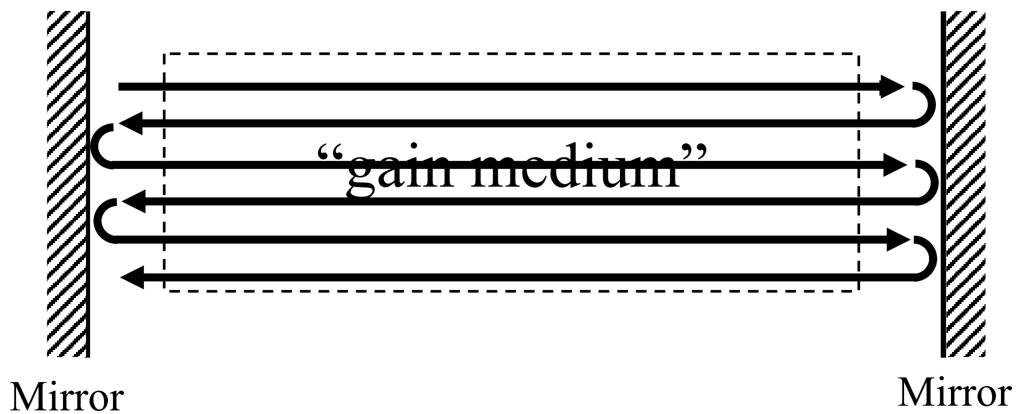


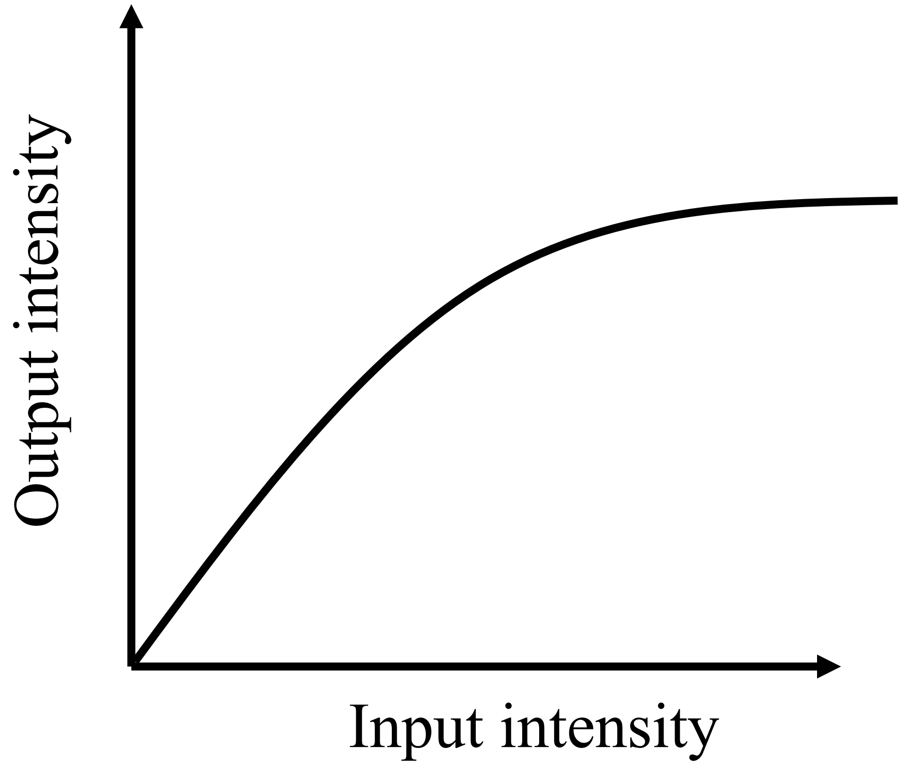
Comments:

1. How long will intensity continue to increase?
2. What about loss at the mirror wall, and elsewhere?
3. How do we get the light out?
4. What if the mirrors are not aligned?
5. Where does the amplification energy come from?



Comments:

1. How long will intensity continue to increase?
   Until gain saturates.
   We will discuss physical reasons for this later in the course.



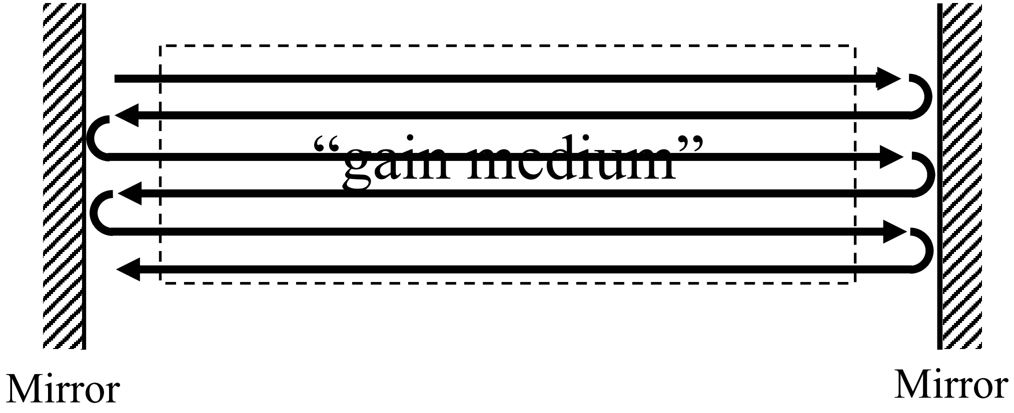
Comments:

2. What about loss at the mirror wall, and elsewhere?

Each trip will have some loss (absorption, scattering), and some gain.

For the laser to work, we need

Net round trip gain > 1



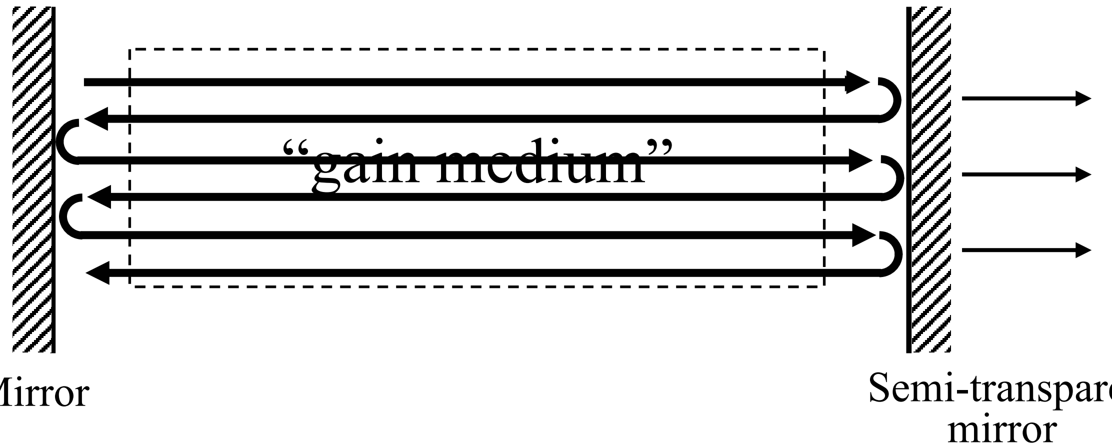
Comments:

3. How do we get the light out?

Pinhole, or semi-transparent mirror.

We will discuss this quantitatively later.

(Any ideas how to make a semi-tranparent mirror?)

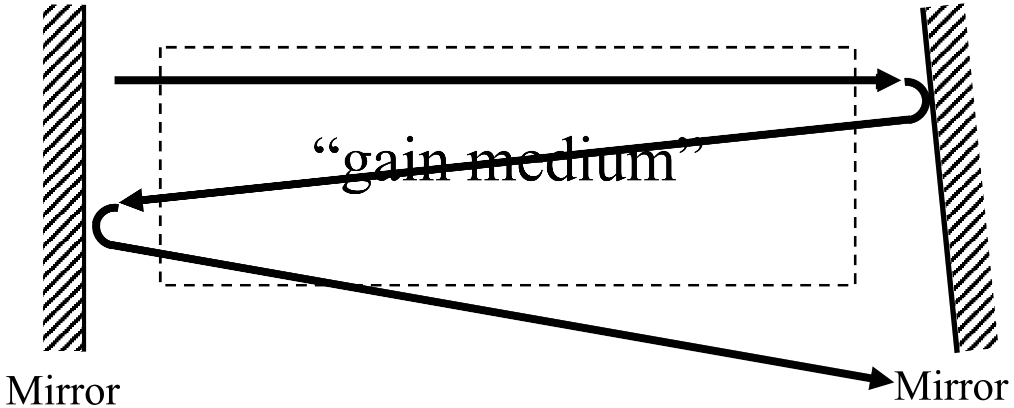


Comments:

4. What if the mirrors are not aligned?

The beam will diverge.

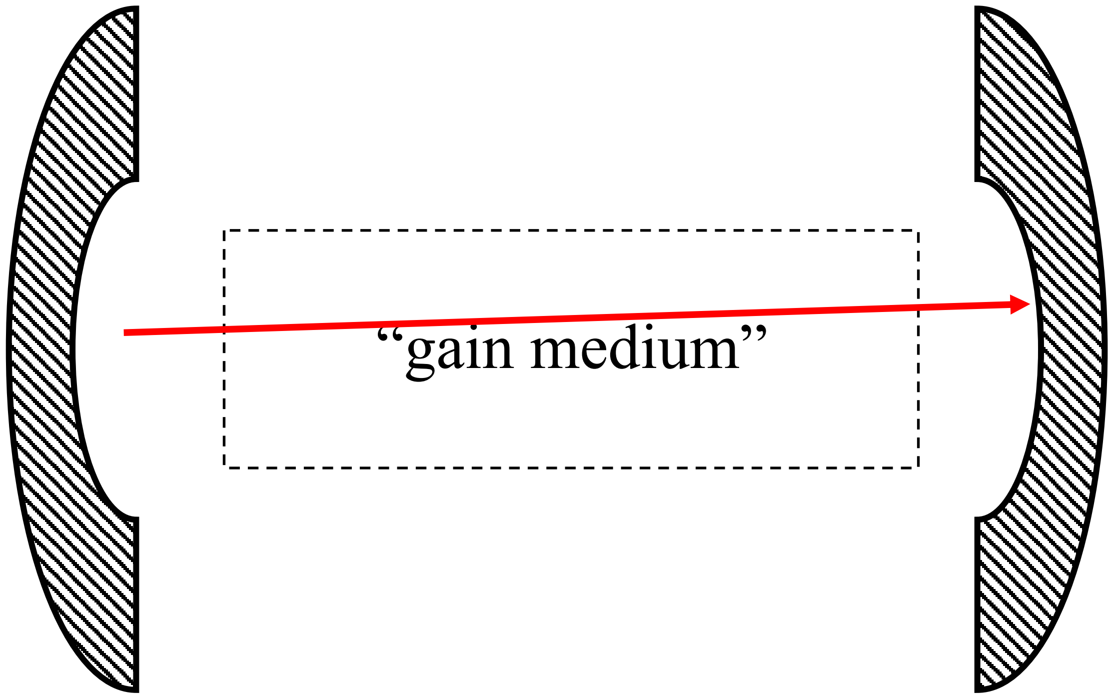
Also, perfectly aligned beam will not stay in place, even if mirrors are perfectly aligned.



Comments:

4. What if the mirrors are not aligned?

One solution: Curved mirrors



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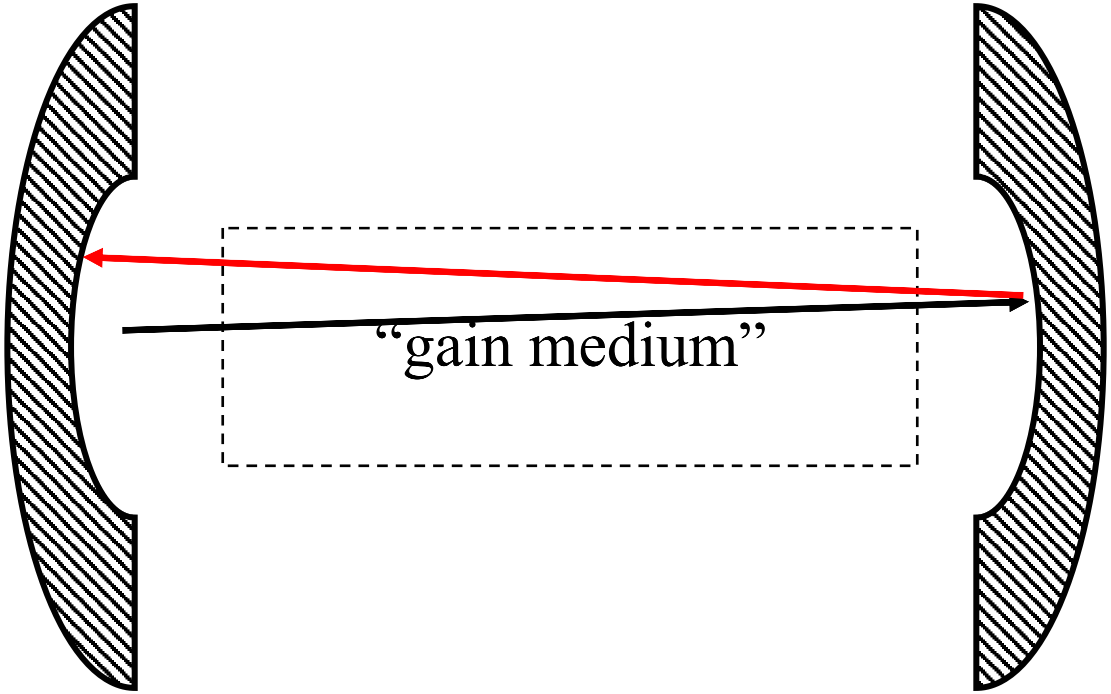

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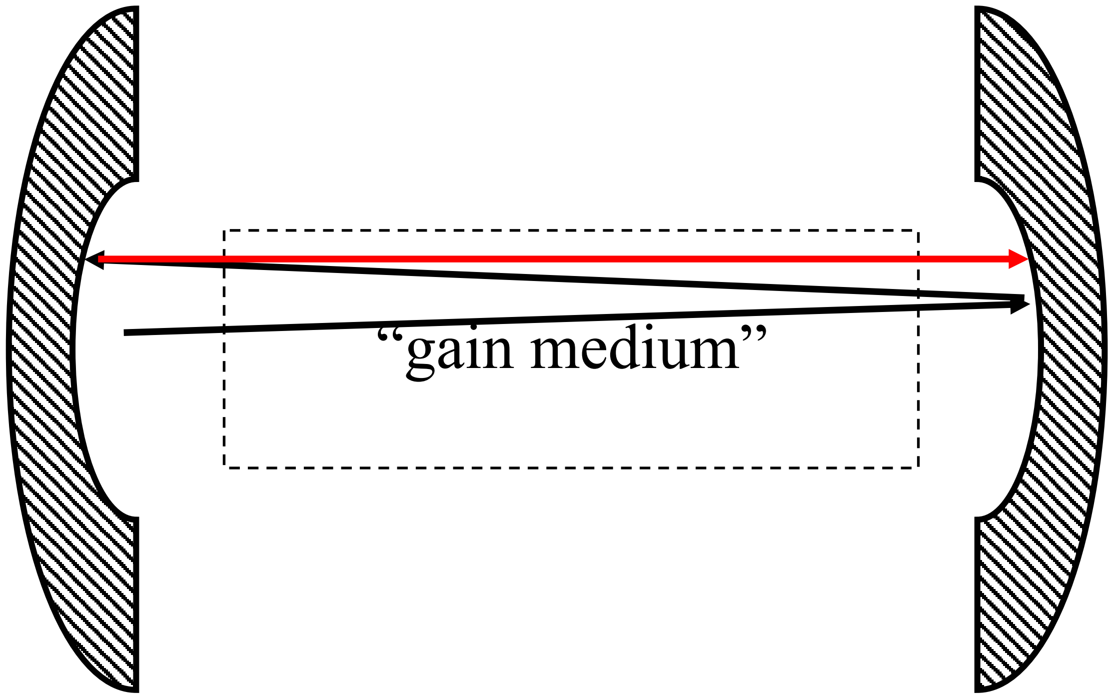

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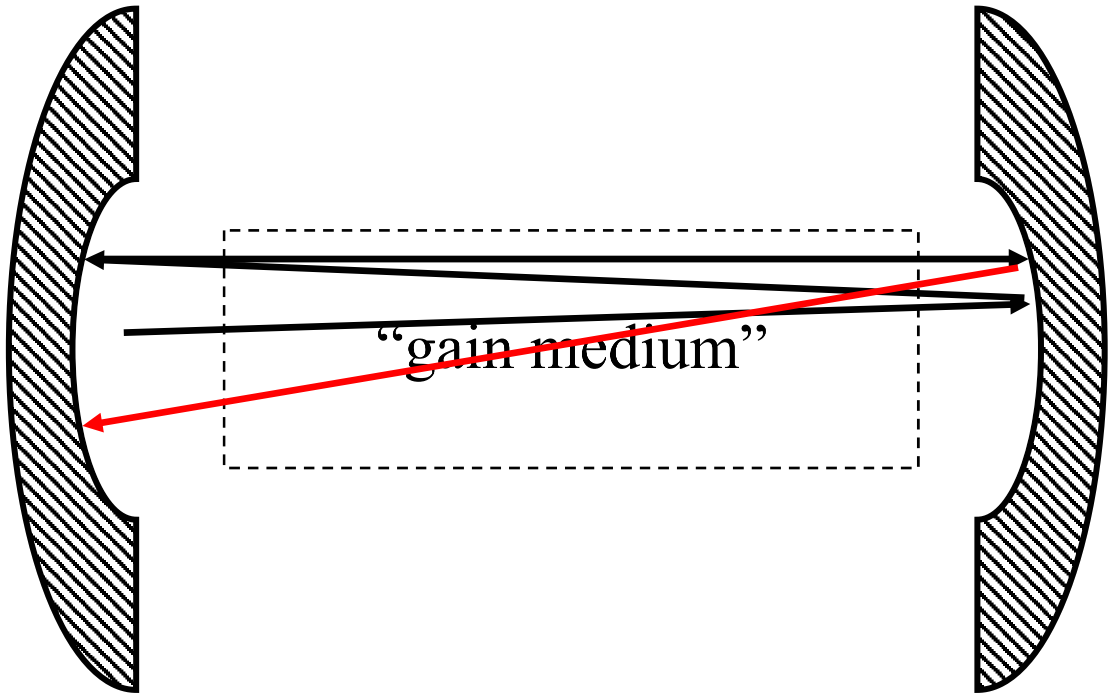

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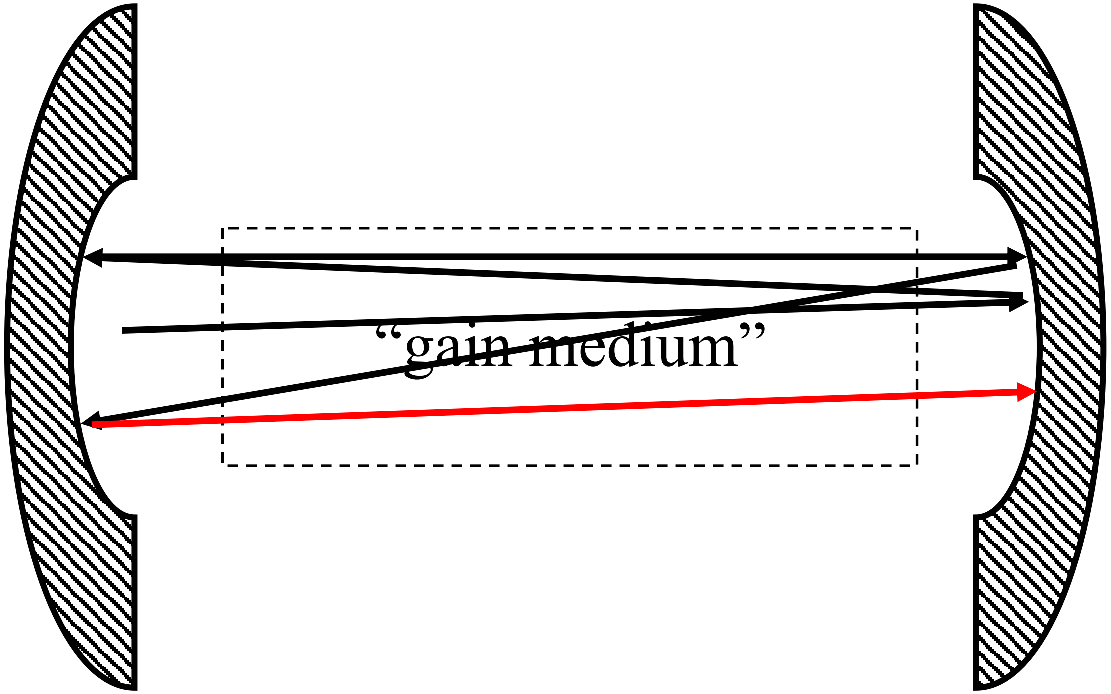

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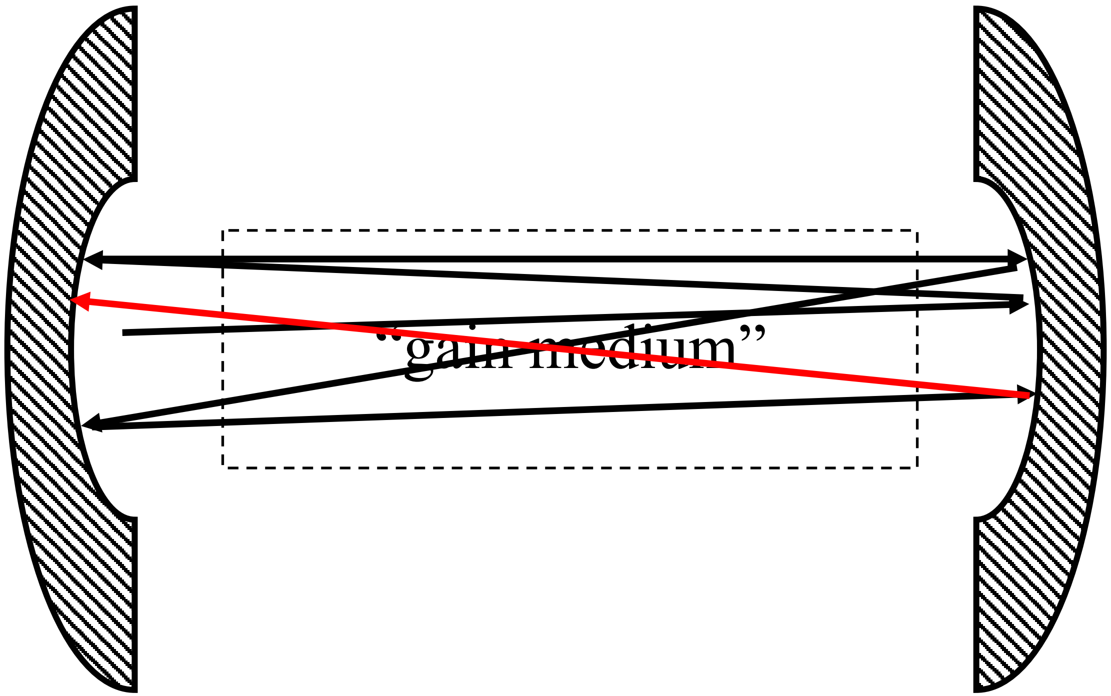
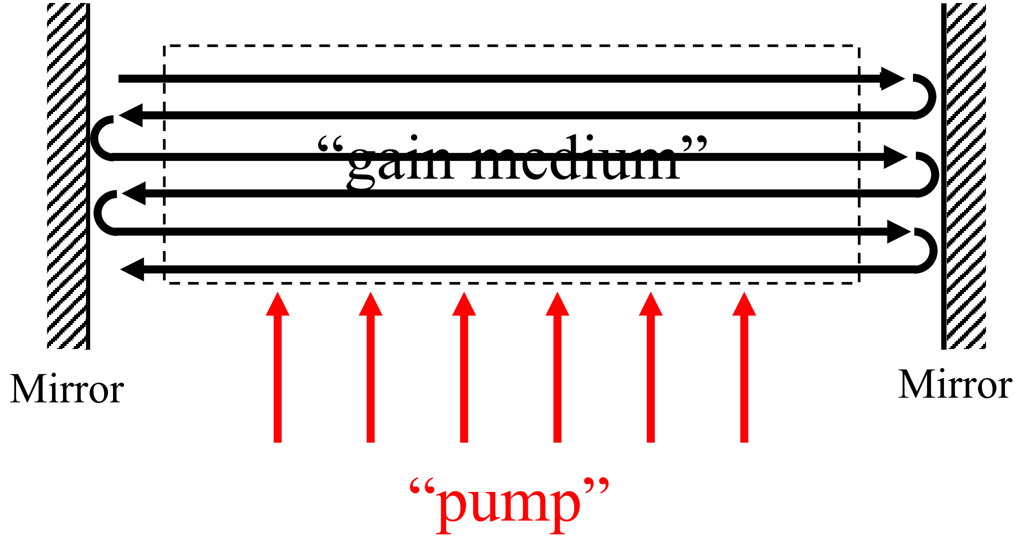


Comments:

5. Where does the amplification energy come from?

We use a "pump" to bring energy into the gain medium.

Two ways to pump: electrically and optically.

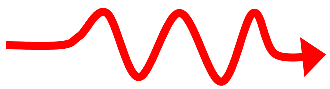


Brief description of a photon:

"Particle of light"

Photon

$E=h\nu$



Planck's constant:
$h=6.6\ 10^{-16}$ eV-s

$\lambda\nu=c$
λ=wavelength
ν=frequency

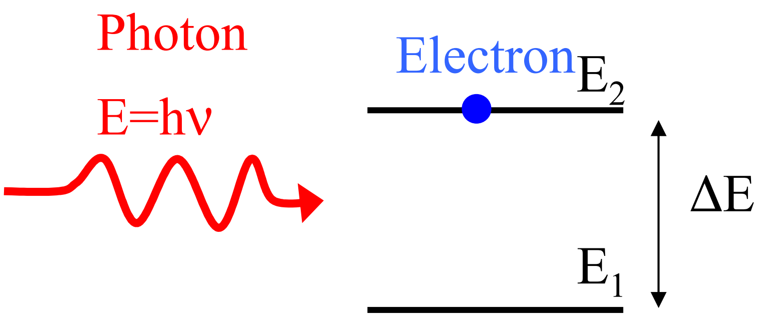
1 eV
$2.4\ 10^{14}$ Hz
1.25 μm
$502\ cm^{-1}$

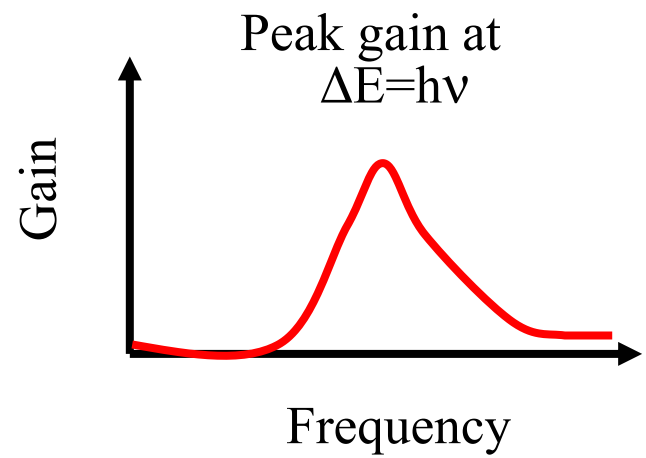
Speed of light:
$c=3\ 10^{8}$ m/s

Wavevector
$k=2\pi/\lambda$

Brief quantum description of gain process:

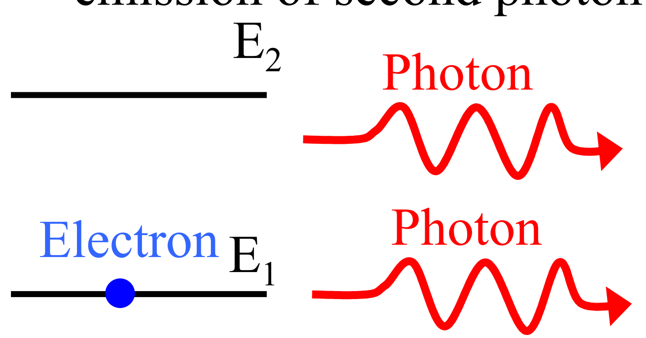
Before:





After:

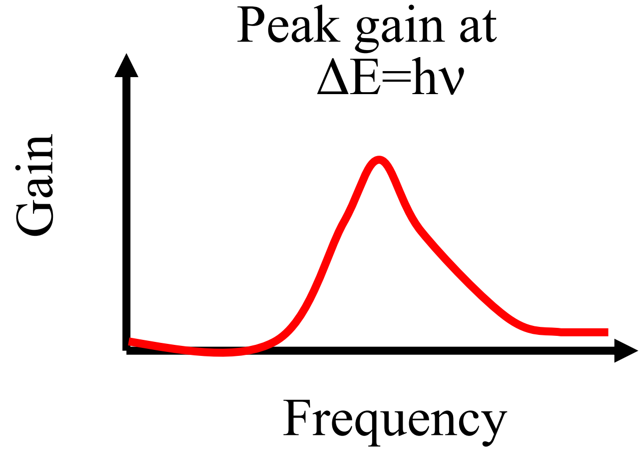
First photon “stimulates” emission of second photon



(We will discuss in detail in lecture 4.)

Very important comments:

- Different atoms and molecules different gain ΔE!
- Electrons in semiconductors can have widely tunable ΔE!



Examples of gain media:

• Neon atoms in a gas (HeNe)	6328 Å
• Chromium atoms in Ruby solid host	6943 Å
• Neodymium atoms in glass/YAG solid host	1.06 μm
• Erbium atoms in glass fiber host	1.5 μm
• Molecular dyes in water or alcohol host	400-1000 Å
• Titanium atoms in a sapphire host	0.7-1.02 μm
• Argon ions in a argon gas	350 – 520 Å
• CO_2 gas	10 μm
• Electrons in semiconductors:	
$Al_xGa_{1-x}As$	0.7-0.9 μm
$In_xGa_{1-x}As_{1-y}P_y$	1.1-1.6 μm
• OH gas molecules	~ 30 cm

A bit of history:

- 10^9 yr. B.C. First lasers were OH molecules, 1.6 GHz, in the cosmos, invented by mother nature. They were "masers": *Microwave Amplification by Stimulated Emission of Radiation*.
- 1954: First manmade maser, Townes Gordon Zeiger, 24 GHz ammonia (NH_4)
- 1960 Ruby laser, Maiman, Hughes Research Laboratory
- 1960 HeNe laser (first cw), Javan et al, Bell Labs

What are some of the properties of lasers that I care about?

- Output is close to a sine wave (linewidths down to 1 Hz can be achieved)
- Output is *coherent*, i.e. phase information is preserved