# Lasers and Photonics
# ECE278, Winter 2002

**Professor & Class Schedule**
**Peter Burke**
**e-mail:** pburke@uci.edu

Lect. Tu/Th 3:30 – 4:50 pm
PSCB 230

Office hours: 5-6 pm, Tu/Th
Office: EG 2232

# Optical communications course sequence

This academic year (2001-2002):

ECE 275A (F): Electro-optic Devices
ECE 278 (W): Lasers and Photonics
ECE 275C (S): Integrated and Fiber Optics

Next academic year (2002-2003):

ECE 275A (F): Optical Communications
ECE 275B (W): Lasers and Photonics
ECE 275C (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 description:** This course will cover the fundamental principles of laser operations, and then discuss specific laser systems. The goal is to equip students with the basic knowledge necessary to understand and use various lasers in their research and/or engineering careers. Therefore, the first half of the course will be very theoretical. Although this is a quickly changing industry, teaching the fundamentals will allow students to understand new technological developments as they occur. During the second half we will cover specific lasers systems and their applications. While we will cover the standard lasers used in physics and chemistry labs and their pulsed operations, there will also be a heavy emphasis on semiconductor lasers and their integration into modern fiber-optics communications systems.

# Course philosophy

A) Course notes on web.

B) 1 slide per minute is usually limit, I will try 0.5 slides per minute. (40 slides per class.) Tell me if I go too fast!

C) Midterm evaluation of the course by outside consultant.

D) I will teach from a physics perspective, and attempt to convey an understanding of how the ***fundamental laws of physics*** can be used to construct lasers. This will empower you to easily achieve your own understanding of many different kinds of lasers, rather than just memorizing which laser works at which wavelength. I will also attempt to give an ***intuition***, leaving the more quantitative results for the homework and reading. This is similar to a technique Feynman used in his Feynman lectures on 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

(Ordered 20 from bookstore? Let me know if we should order more.)

Optional: (On reserve at the library. Let me know if it is working out!)

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. (Not on reserve; the library does not own this one.)

# Grading

- Homework 40%
- Midterm 30%
- Final 30%

# Outline:

## Most Laser Courses and Books:

Maxwell’s equations, wave propagation

Gaussian beams

Matrix description of beams

Ray tracing

Optical resonators

Interaction of radiation with matter

Amplification, lasers.

Various kinds of lasers, pumping schemes for rest of quarter.

This leaves you with lots of math but you don’t actually get to lasers until the middle of the term!

## This class:

Generally, I will start with a description of lasers and the physics of light/matter interaction, then discuss the mathematical details of the optical cavities, beam propagation, etc.

# Course outline

Lecture 1: Introduction
Lecture 2: Classical review of electromagnetic waves (Maxwell's equations)
Lecture 3: Quantum description of electromagnetic waves (photons)
Lecture 4: Atomic physics and the interaction of radiation with matter
Lecture 5: Gaussian beams
Lecture 6: Guided wave propagation: fibers, waveguides
Lecture 7: Fiber amplifiers
Lecture 8: Optical resonators
Lecture 9: More optical resonators
MIDTERM
Lecture 10: Laser oscillation
Lecture 11: More laser oscillation
Lecture 12: Some specific laser systems: HeNe, Ti:Saphire
Lecture 13: Semiconductors: Band theory, Bloch theorem
Lecture 14: p-n junctions, p-n lasers. Quantum well lasers
Lecture 15: VCSELs, quantum cascade lasers
Lecture 16: Integration into optical communications systems: modulation and detection
Lecture 17: Quantum optics: quantum description of thermal and laser radiation
Lecture 18: More quantum optics
Lecture 19: Open
Lecture 20: Open

# 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:

*Light Amplification by Stimulated Emission of Radiation*

Step 1: Build a "cavity":

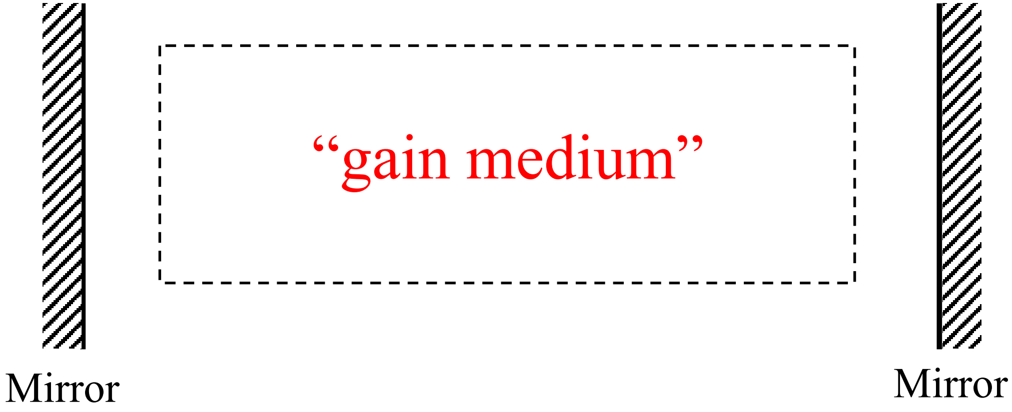
# LASERS:

*Light Amplification by Stimulated Emission of Radiation*

Step 1: Build a "cavity":

Step 2: Insert a "gain medium"

(special atoms in liquid, solid, or gas)



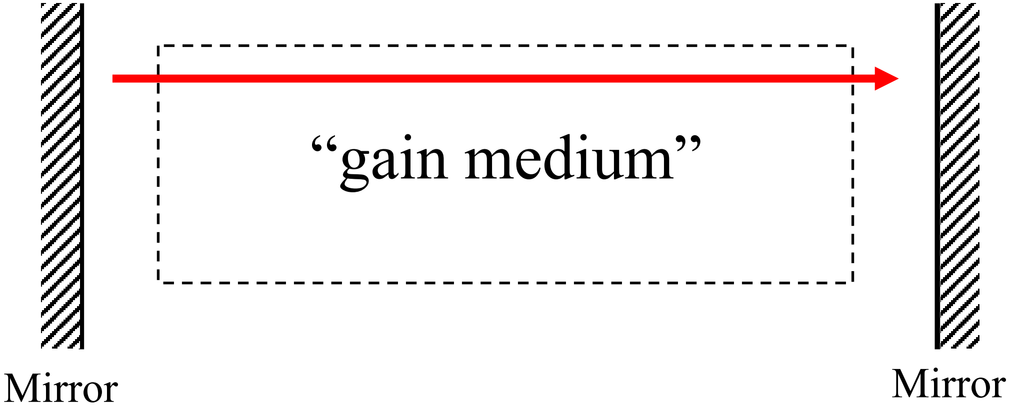
# LASERS:

*Light Amplification by Stimulated Emission of Radiation*

Step 1: Build a “cavity”:

Step 2: Insert a “gain medium”

Step 3: Start it up! (How?)



# LASERS:

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

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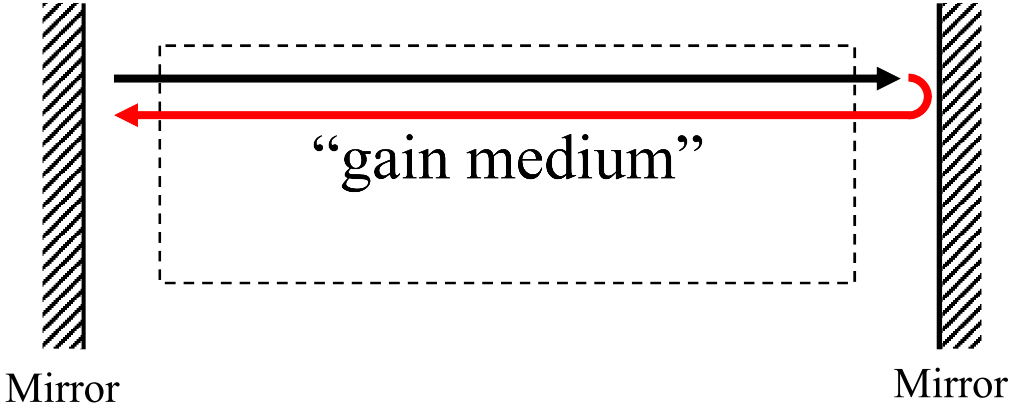

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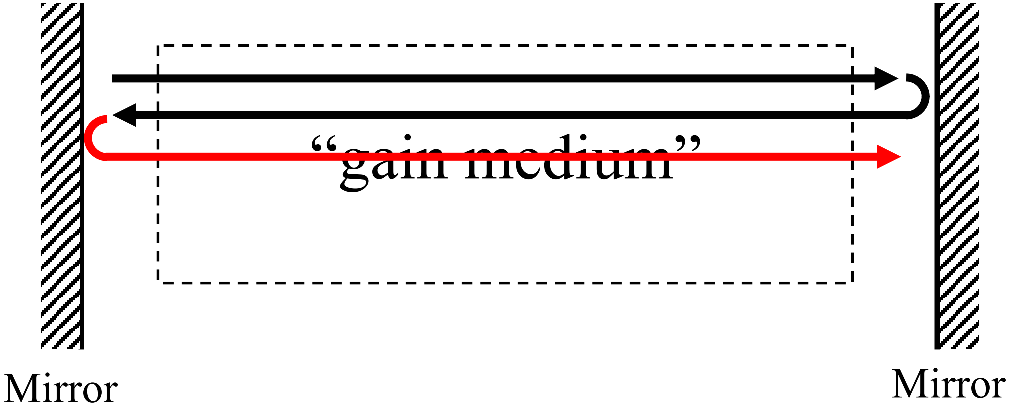

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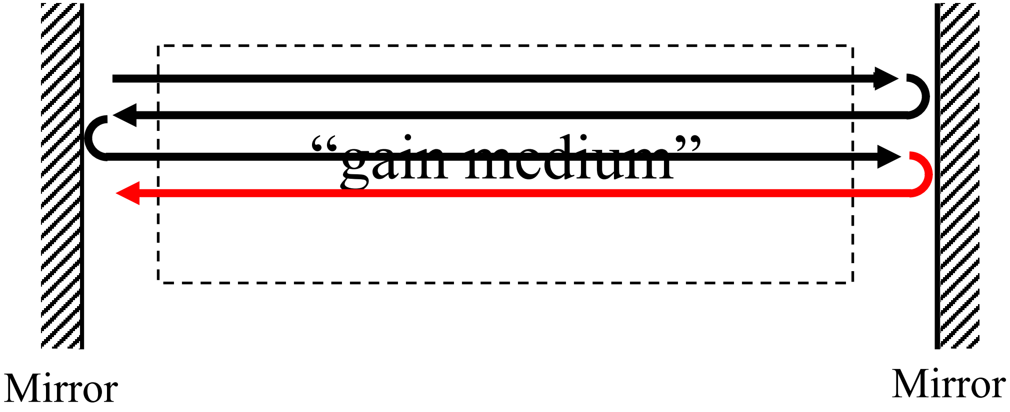

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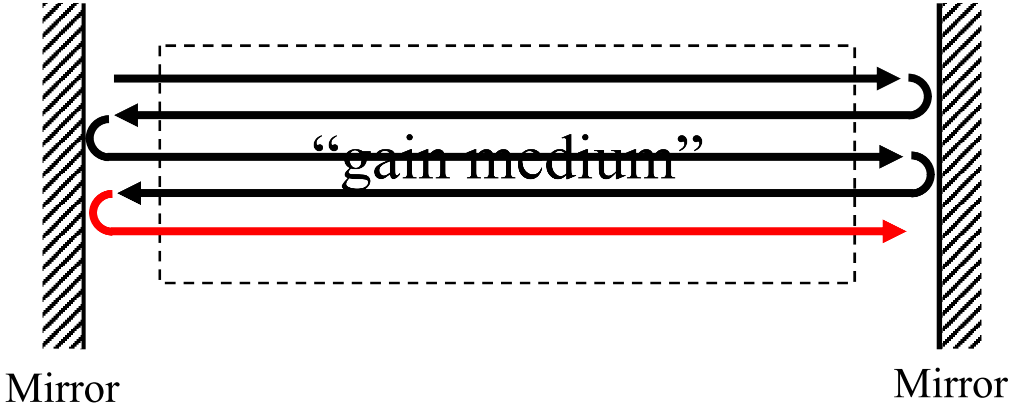

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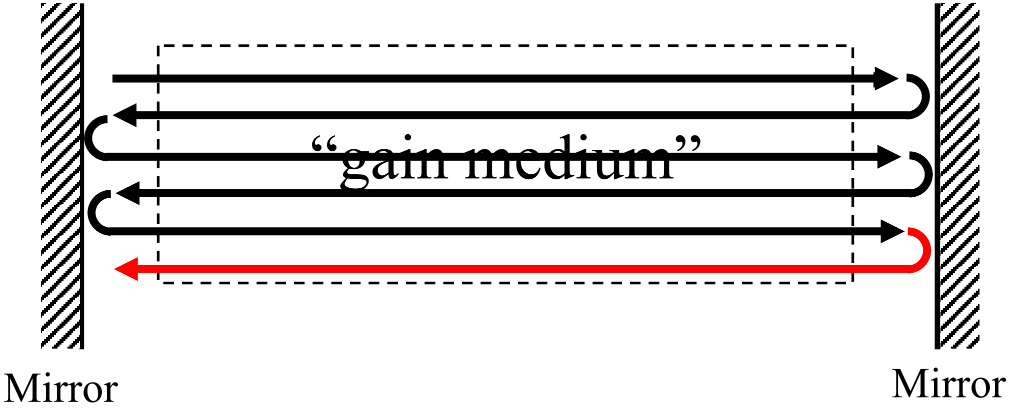

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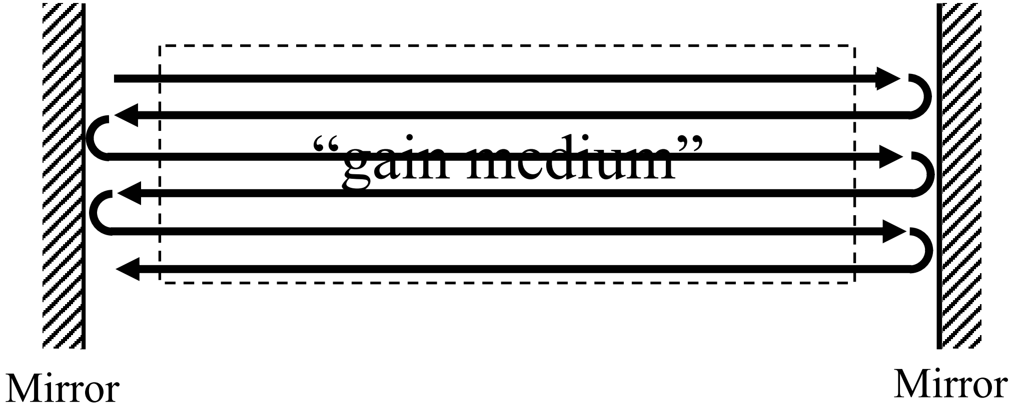
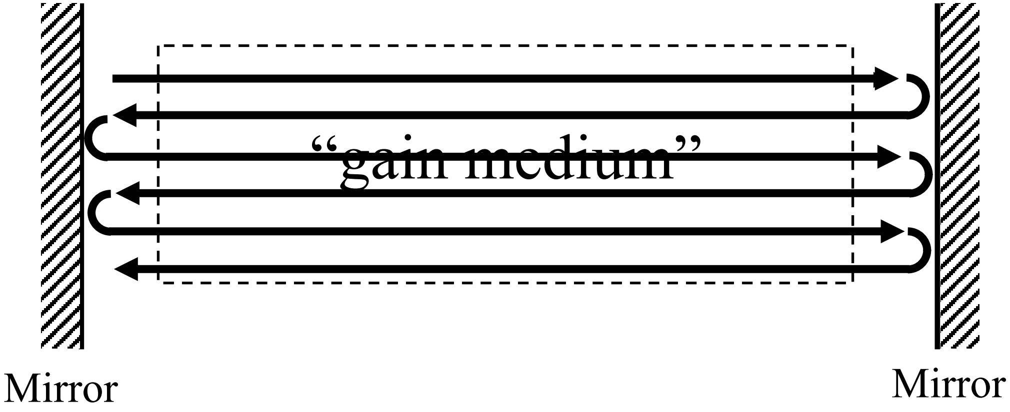


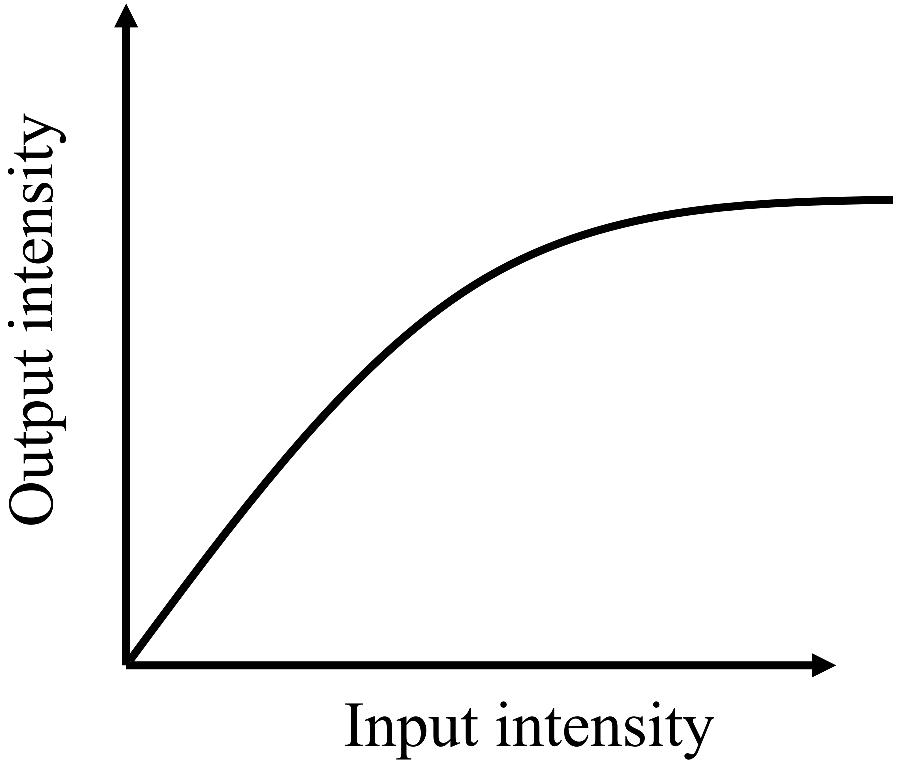
# Comments:

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.



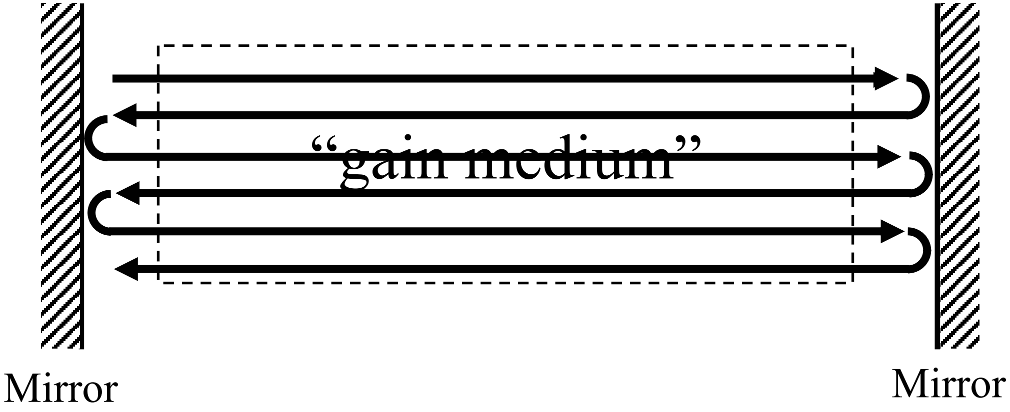
# Comments:

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



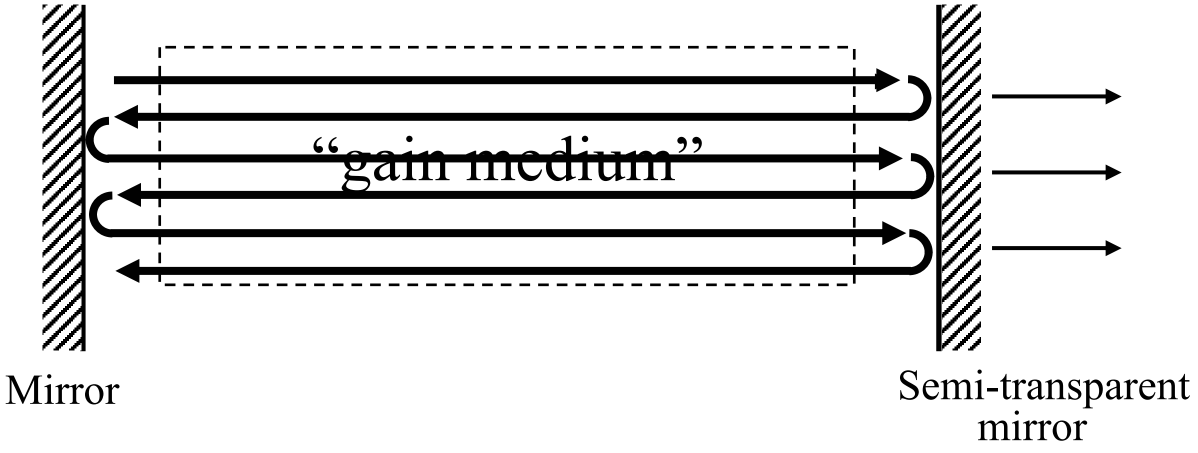
# Comments:

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?)

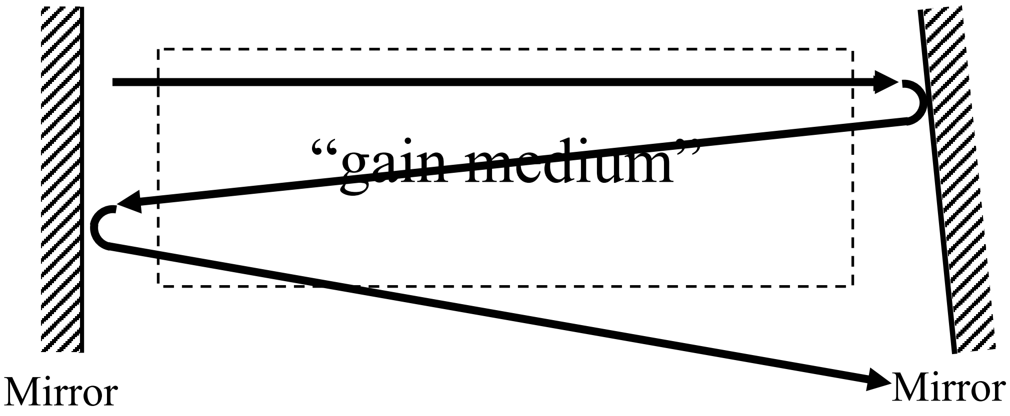


# Comments:

4. What if the mirrors are not aligned?

The beam will diverge.

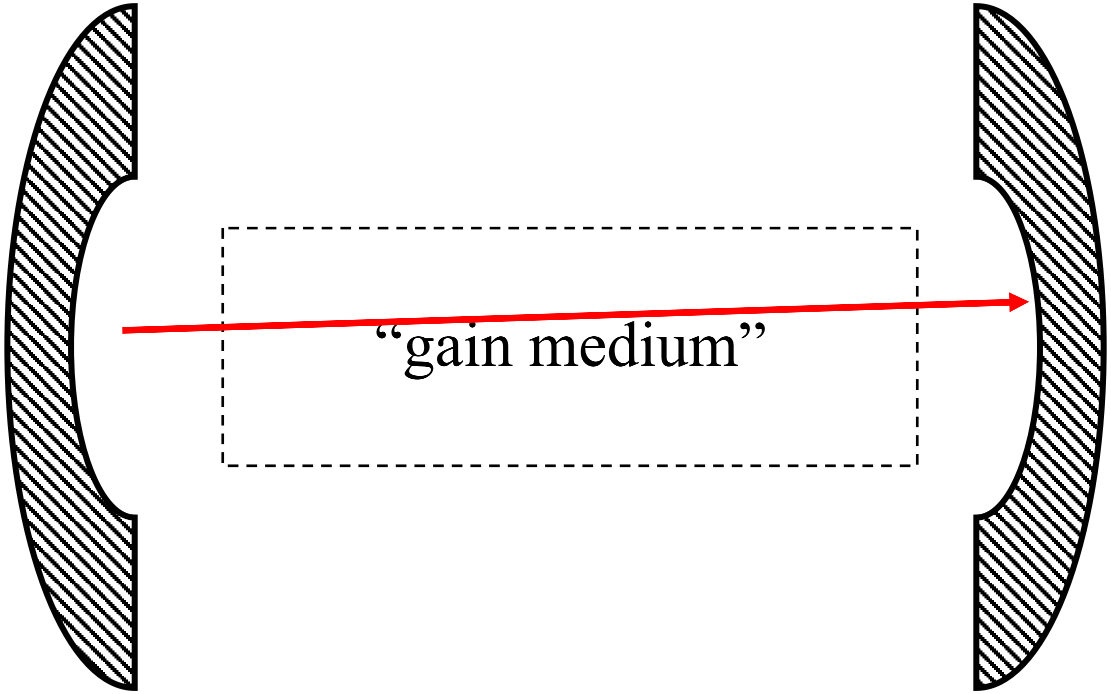
Also, perfectly aligned beam will not stay in place, even if mirrors are perfectly aligned.



# Comments:

4. What if the mirrors are not aligned?

One solution: Curved mirrors



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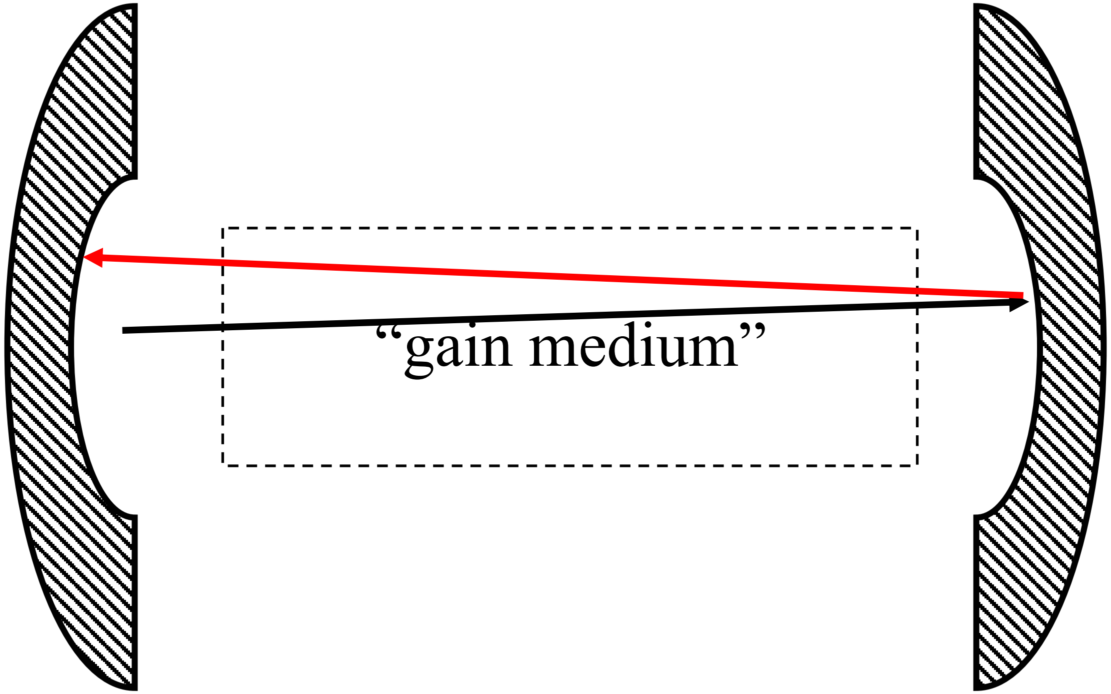

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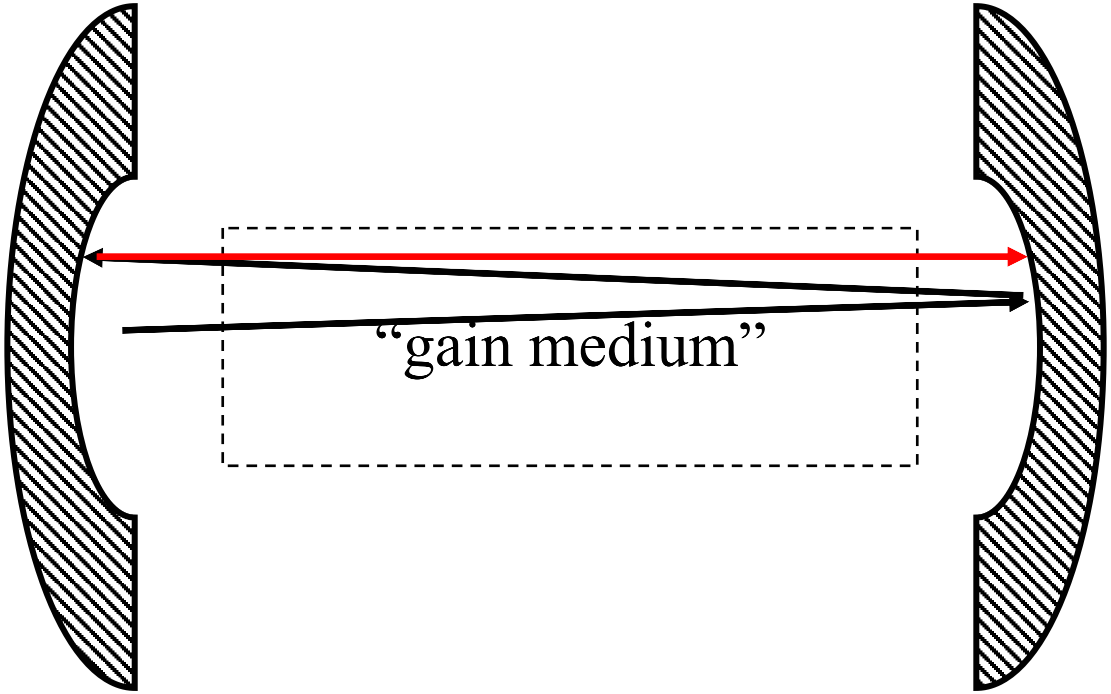

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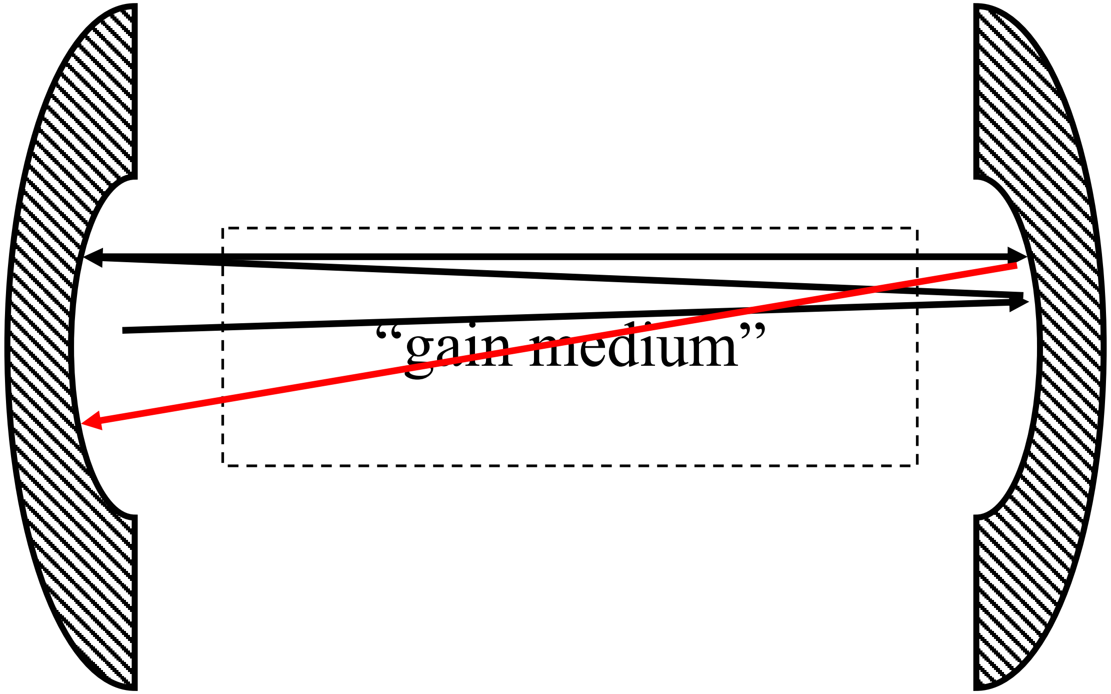

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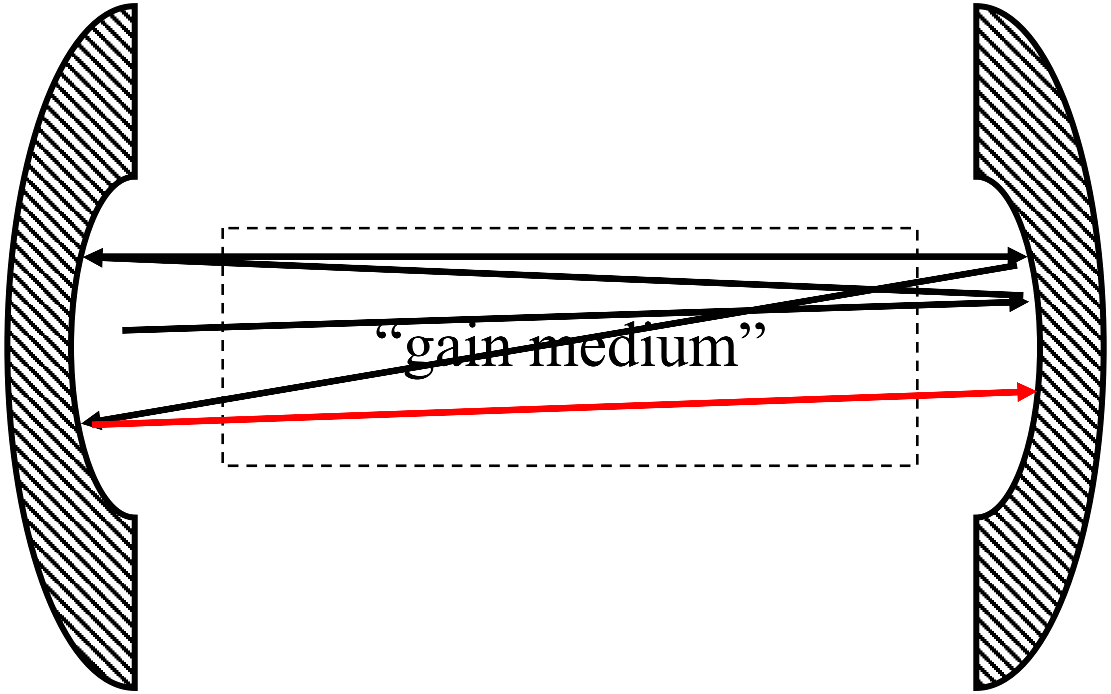
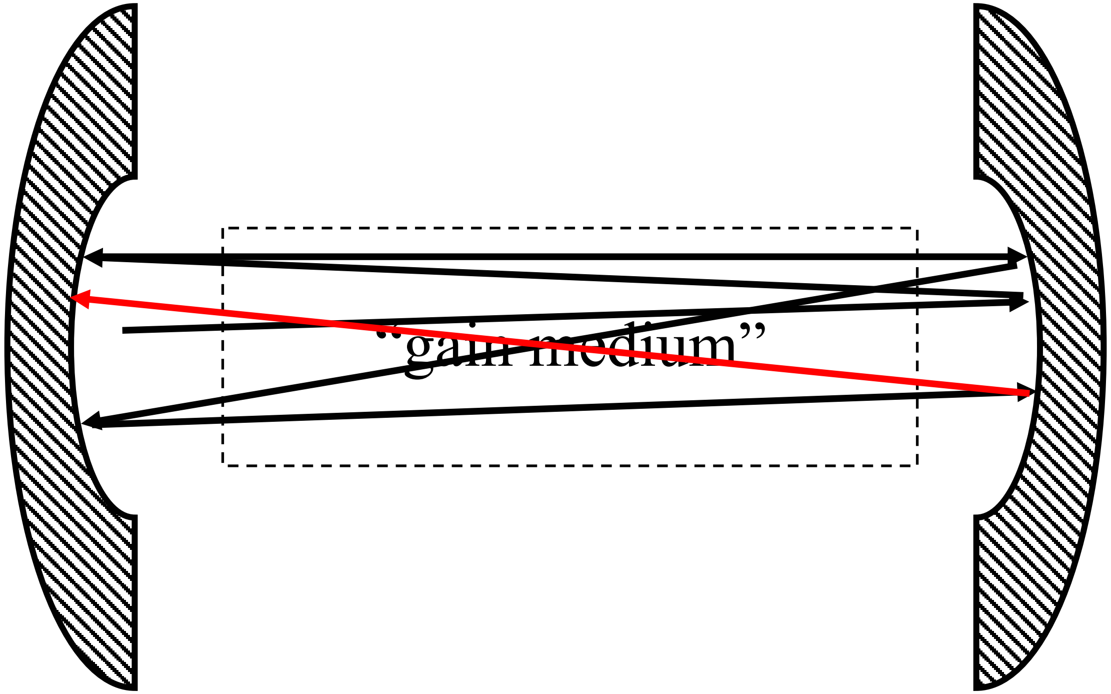


# Comments:

4. What if the mirrors are not aligned?

One solution: Curved mirrors

We will discuss this mathematically in lecture 6.

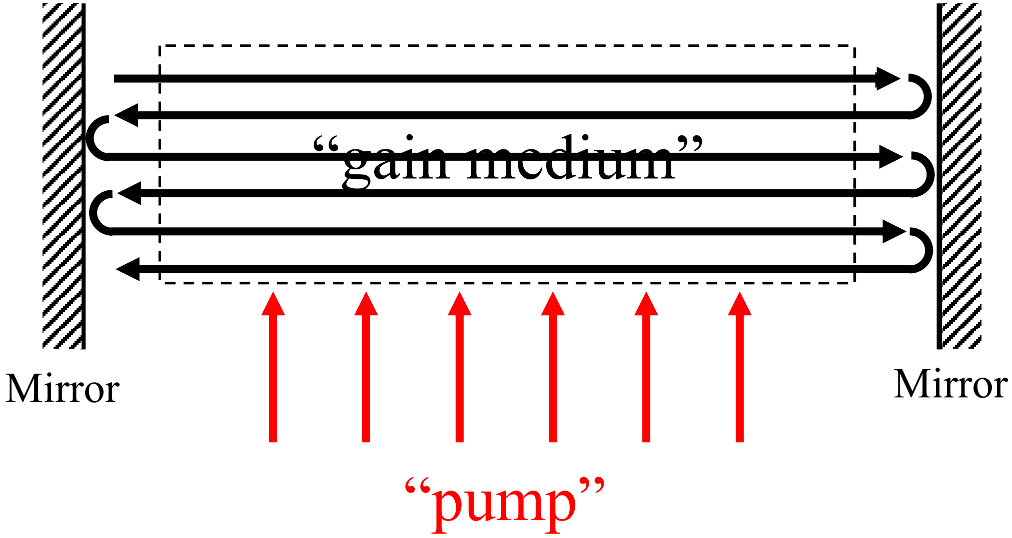


# Comments:

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.

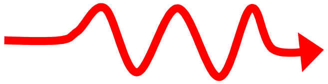


# Brief description of a photon:

"Particle of light"

Photon

$E=h\nu$



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

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

1 eV

$2.4\ 10^{14}$ Hz

1.25 μm

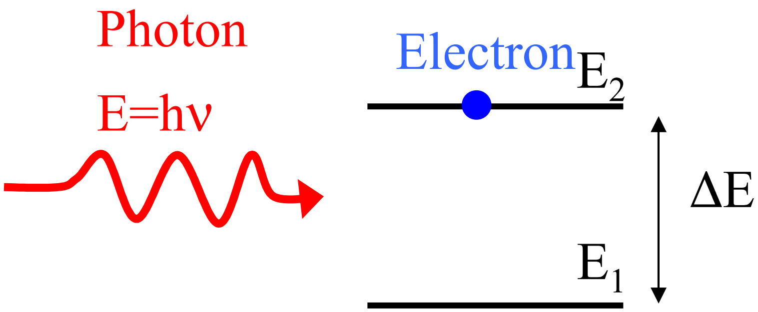
502 $cm^{-1}$

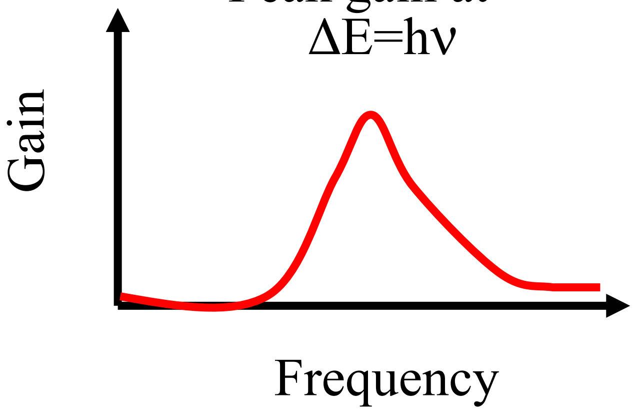
Speed of light:
$c=3\ 10^{8}$ m/s

Wavevector
$k=2\pi/\lambda$

# Brief quantum description of gain process:

Before:

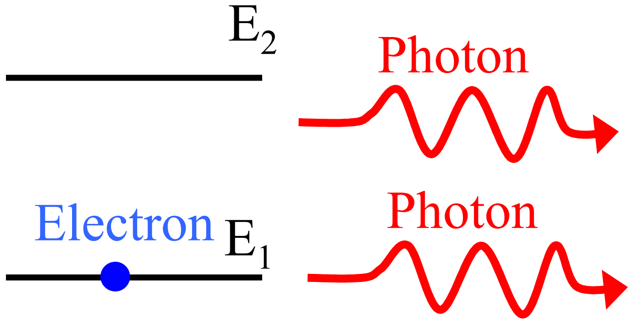




Peak gain at
$\Delta E = h\nu$

After:

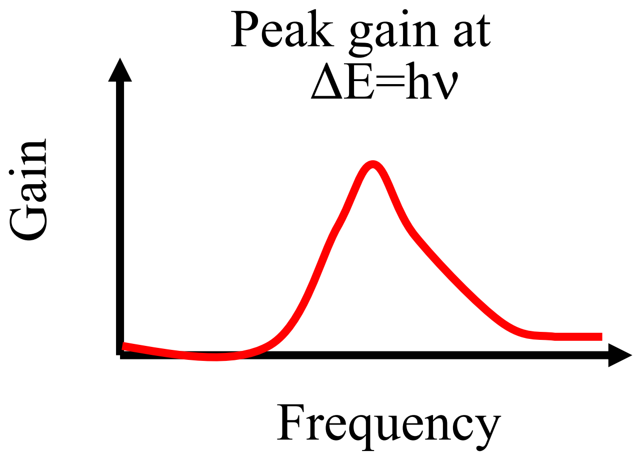
First photon "stimulates"
emission of second photon



(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”: *<u>M</u>icrowave <u>A</u>mplification by <u>S</u>timulated <u>E</u>mission of <u>R</u>adiation*.
- 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

**Data Sheet**
**January 2001**

# A1112 High-Power 1550 nm DFB Source Lasers

## Description

The A1112 1550 nm DFB laser modules are high-power devices in a 14-pin butterfly package with a thermoelectric cooler and monitor photodiode. The lasers are designed to be used in conjunction with commercially available external modulators for high-performance analog and digital applications. Agere Systems Inc. offers modules with 30 mW or 40 mW output power coupled into polarization-preserving fiber. The A1112 operates with positive or negative bias.

## Features

- High fiber-coupled power, 30 mW and 40 mW
- Narrow linewidth, <3 MHz
- Low relative intensity noise, < –162 dB/Hz
- Coupled to polarization-preserving (PANDA-type fiber)

## Applications

- Externally modulated CATV transmitters
- Externally modulated analog and digital communication links

## Absolute Maximum Ratings

Stresses in excess of the absolute maximum ratings can cause permanent damage to the device. These are absolute stress ratings only. Functional operation of the device is not implied at these or any other conditions in excess of those given in the operational sections of the data sheet. Exposure to absolute maximum ratings for extended periods can adversely affect device reliability.

| Parameter | Symbol | Min | Max | Unit |
|---|---|---|---|---|
| Operating Case Temperature Range | $T_C$ | –20 | 65 | °C |
| Storage Temperature Range | Tstg | –40 | 70 | °C |
| Forward Current (Laser) | $I_F$ | | | |
| A1112PB, A1112NB | | — | 275 | mA |
| A1112PC, A1112NC | | — | 400 | mA |
| Reverse Voltage (Laser) | $V_R$ | — | 2.0 | V |
| Photodiode Reverse Voltage | $V_{RPD}$ | — | 10 | V |
| TEC Voltage | $V_{TEC}$ | — | 2.0 | V |
| TEC Current | $I_{TEC}$ | | | |
| Cooling | | — | 1.8 | A |
| Heating | | — | 1.5 | A |

## Electrical/Optical Characteristics

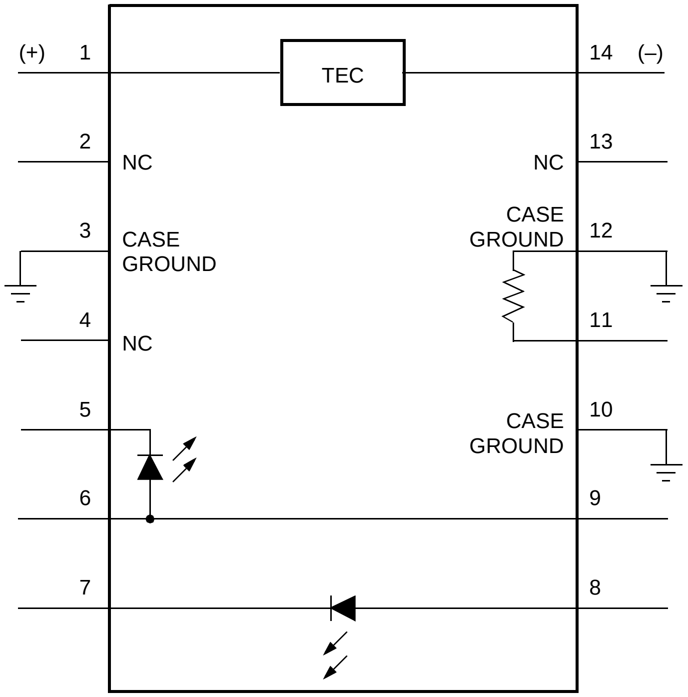
**Table 1. Optical Characteristics** (25 °C Case Temperature)

| Parameter | Symbol | Conditions | Min | Max | Unit |
|---|---|---|---|---|---|
| Optical Output Power | $P_O$ | | | | |
| A1112PB, A1112NB | | — | 30 | — | mW |
| A1112PC, A1112NC | | — | 40 | — | mW |
| Center Wavelength | $\lambda_C$ | $I_{OP}$ | 1540 | 1560 | nm |
| Linewidth (FWHM) | $\Delta_V$ | $I_{OP}$ | — | 3 | MHz |
| Side Mode Suppression Ratio | SMSR | $I_{OP}$ | 30 | — | dB |
| Relative Intensity Noise | RIN | $I_{OP}$, 40 MHz to 860 MHz | — | –162 | dBc/Hz |
| Operating Current | $I_{OP}$ | — | — | 250/350 | mA |
| Threshold Current | $I_{TH}$ | — | — | 35/40 | mA |
| Forward Voltage | $V_F$ | — | — | 2.5/3.0 | V |
| Optical Isolation | — | –20 °C to +65°C | 30 | — | dB |
| Polarization Extinction Ratio | $T_E/T_M$ | From fiber end, $I_{OP}$ | 20 | — | dB |
| Reverse Voltage | $V_R$ | — | — | 2.0 | V |

**Table 2. Electrical Characteristics**

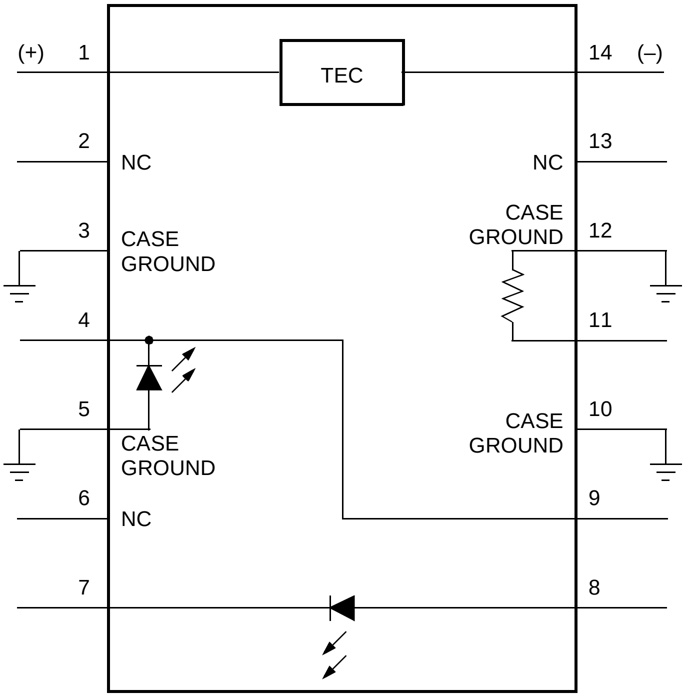
| Parameter | Symbol | Condition | Min | Max | Unit |
|---|---|---|---|---|---|
| Monitor Photodiode Reverse Voltage | $V_{RMPD}$ | Iop | — | 10 | V |
| Monitor Photodiode Current | $I_{MPD}$ | — | 40 | 2000 | µA |
| TEC Current | $I_{TEC}$ | ΔT = 40 °C | — | 1.8 | A |
| TEC Voltage | $V_{TEC}$ | ΔT = 40 °C | — | 2.2 | V |
| Thermistor Resistance | $R_{TH}$ | 25 °C | 9.0 | 11.0 | kΩ |

## Electrical/Optical Characterisitics (continued)



1-1232(F)

**Figure 1. A1112 Laser Positive Bias Ciicuit Schematic**

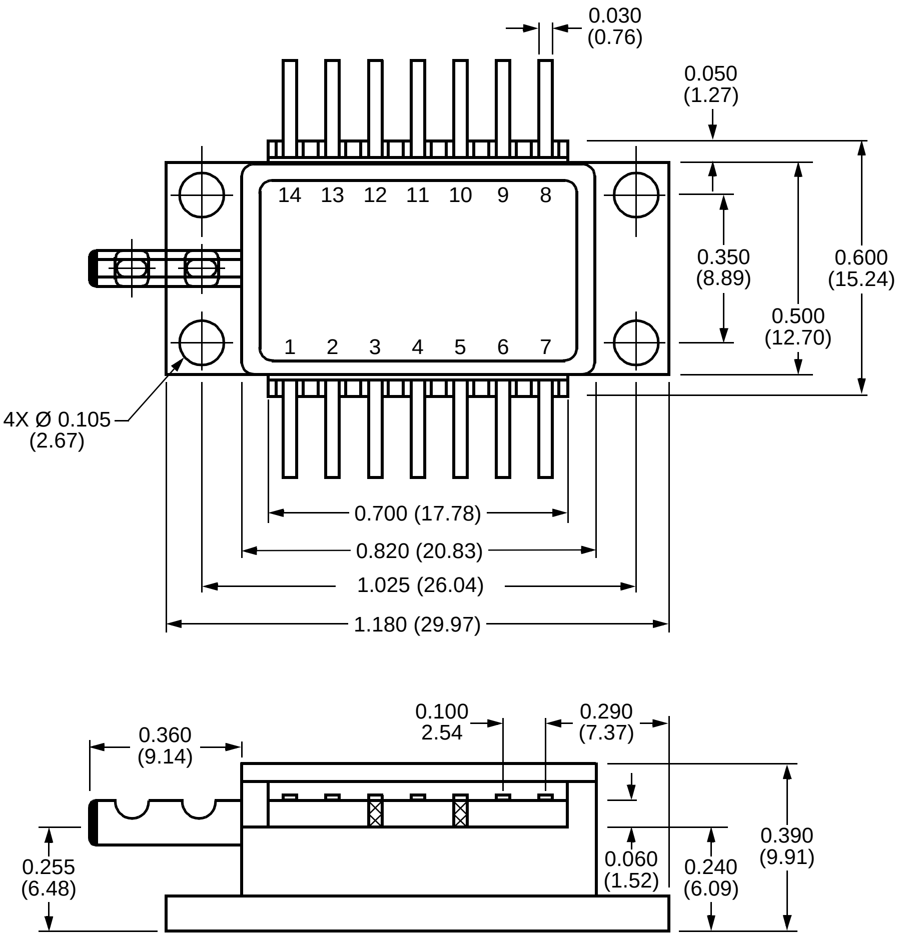


1-1232(F).a

**Figure 2. A1112 Laser Negative Bias Ciicuit Schematic**

## Outline Diagram

Dimensions are in inches and (millimeters).



1-1177(F)

## Pin Information

**Table 3. Pin Descriptions**

| Pin No. | A1112 (Positive Bias) | A1112 (Negative Bias) | Pin No | A1112 (Positive Bias) | A1112 (Negative Bias) |
|---|---|---|---|---|---|
| 1 | TE Cooler (+) | TE Cooler (+) | 8 | Photodiode Anode | Photodiode Anode |
| 2 | NC | NC | 9 | Laser Anode | Laser Cathode |
| 3 | Case Ground | Case Ground | 10 | Case Ground | Case Ground |
| 4 | NC | Laser Cathode | 11 | Thermistor | Thermistor |
| 5 | Laser Cathode, Case Ground | Laser Anode, Case Ground | 12 | Case Ground | Case Ground |
| 6 | Laser Anode | NC | 13 | NC | NC |
| 7 | Photodiode Cathode | Photodiode Cathode | 14 | TE Cooler (–) | TE Cooler (–) |

## Laser Safety Information

## Class IIIb Laser Product

FDA/CDRH Class IIIb laser product. All versions are Class IIIb laser products per CDRH, 21 CFR 1040 Laser Safety requirements. All versions are Class 3B laser products per *IEC*[1] 60825-1:1993. The device has been classified with the FDA under an accession number to be determined.

This product complies with 21 CFR 1040.10 and 1040.11.
*Fujikura*[2] PANDA single-mode fiber pigtail, 1 m—2 m; FC/APC connector, nonaligned
Wavelength = 1.5 µm
Maximum power = 60 mW

Because of size constraints, laser safety labeling (including an FDA Class IIIb label) is not affixed to the module but attached to the outside of the shipping carton.

Product is not shipped with power supply.

**Caution**: **Use of controls, adjustments, and procedures other than those specified herein may result in hazardous laser radiation exposure.**

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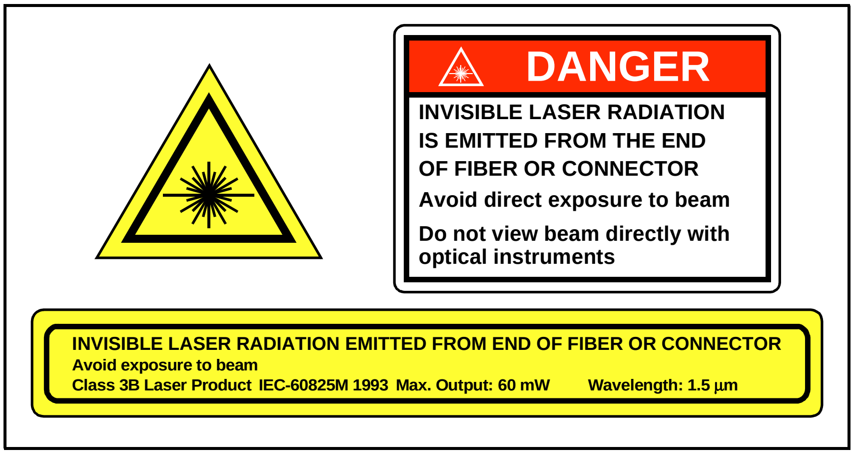
[1] *IEC* is a registered trademark of The International Electrotechnical Commission.
[2] *Fujikura* is a registered trademark of Fujikura LTD.



DANGER

INVISIBLE LASER RADIATION
IS EMITTED FROM THE END
OF FIBER OR CONNECTOR

Avoid direct exposure to beam

Do not view beam directly with optical instruments

INVISIBLE LASER RADIATION EMITTED FROM END OF FIBER OR CONNECTOR
Avoid exposure to beam
Class 3B Laser Product IEC-60825M 1993 Max. Output: 60 mW Wavelength: 1.5 µm

## Ordering Information

### Table 4. Ordering Information[1]

| Device Code | Output Power/Laser Bias | Fiber/Connector | Comcode |
|---|---|---|---|
| A1112PB | 30 mW/ Positive Laser Bias | *Fujikura* PANDA/ FC/APC nonaligned | 108846536 |
| A1112PC | 40 mW/ Positive Laser Bias | | 108846544 |
| A1112NB | 30 mW/ Negative Laser Bias | | 108846510 |
| A1112NC | 40 mW/ Negative Laser Bias | | 108846528 |

1. For additional ordering information, please contact an account manager at Opto West, Agere Systems, 1-800-362-3891 (for sales staff, please press option 2).

For additional information, contact your Agere Systems Account Manager or the following:

INTERNET: **http://www.agere.com**
E-MAIL: **docmaster@micro.lucent.com**
N. AMERICA: Agere Systems Inc., 555 Union Boulevard, Room 30L-15P-BA, Allentown, PA 18109-3286
**1-800-372-2447**, FAX 610-712-4106 (In CANADA: **1-800-553-2448**, FAX 610-712-4106)
ASIA PACIFIC: Agere Systems Singapore Pte. Ltd., 77 Science Park Drive, #03-18 Cintech III, Singapore 118256
**Tel. (65) 778 8833**, FAX (65) 777 7495
CHINA: Agere Systems (Shanghai) Co., Ltd., 33/F Jin Mao Tower, 88 Century Boulevard Pudong, Shanghai 200121 PRC
**Tel. (86) 21 50471212**, FAX (86) 21 50472266
JAPAN: Agere Systems Japan Ltd., 7-18, Higashi-Gotanda 2-chome, Shinagawa-ku, Tokyo 141, Japan
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Technical Inquiries: OPTOELECTRONICS MARKETING: **(44) 1344 865 900** (Ascot UK)

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