



# Chemistry 4631

## Instrumental Analysis

### Lecture 10

# Components of Optical Instruments

## UV to IR

### Basic components of spectroscopic instruments:

- stable source of radiant energy
- transparent container to hold sample
- device to isolate selected region of the spectrum for measurement
- detector to convert radiant energy to a signal
- signal processor and readout

# Components of Optical Instruments

## Photon Transducers

which respond to radiation:

- Phototubes (emission of electrons from a photosensitive solid)
- Photomultiplier tubes
- Photovoltaic cells (current generated at the interface of a semiconductor layer)
- Photoconductivity (production of electrons and holes in a semiconductor)
- Silicon photodiodes (conductance across a reverse bias pn junction)
- Charge transfer (charge develops in silicon crystal)

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# Components of Optical Instruments

## Silicon Diode Transducers

**A reverse-biased pn junction (pn diode) on a silicon chip can be fabricated to act as a detector.**

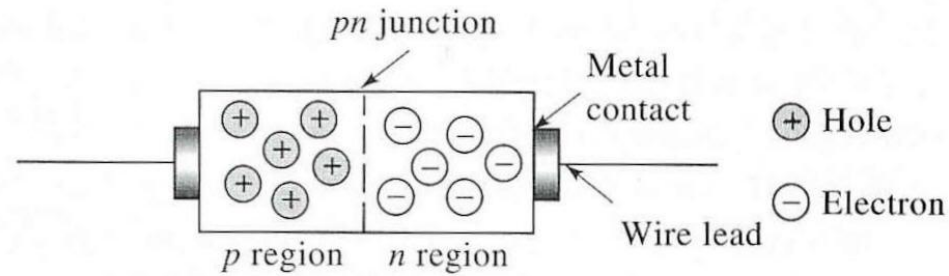
**When a reverse-bias is applied, a depletion layer forms.**

# Components of Optical Instruments

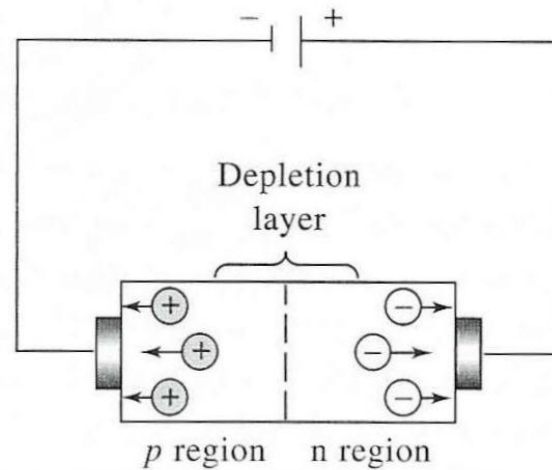
## Silicon Diode Transducers

UV and vis photons have enough energy to create holes or electrons when striking the depletion layer of a pn junction.

The holes and electrons formed in the depletion layer migrate to the connecting leads and produce a current.



(a)



Reverse bias

(b)

**Figure 7-30** (a) Schematic of a silicon diode. (b) Formation of depletion layer, which prevents flow of electricity under reverse bias.

# Components of Optical Instruments

## Silicon Diode Transducers

The spectral range: 190 to 1100 nm

Spectral response - an important characteristic of any photo-detector.

Measures how the photocurrent, varies with the wavelength of incident light.

Frequency response - measures how rapidly the detector can respond to a time varying optical signal.

# Components of Optical Instruments

## Silicon Diode Transducers

### (p-i-n and avalanche photodiodes)

A silicon photodiode designed with gain – uses relatively high reverse bias (10-100 V) to accelerate electrons through the crystal lattice and create more through impact ionization.

The i-region is very lightly doped (it is effectively intrinsic).

The diode is designed such that most of the light is absorbed in the i-region.

# Components of Optical Instruments

## Silicon Diode Transducers

### (p-i-n and avalanche photodiodes)

Under reverse bias, the i-region is depleted, and the carriers generated in the i-region are collected rapidly due to the strong electric field.

p-i-n diodes operating at  $1.3 \mu\text{m}$  and  $1.55 \mu\text{m}$  are used extensively in optical fiber communications.

However arrays of avalanche photodiodes are approaching gains of PMTs and called silicon photomultipliers (SiPMs).

SiPMs – gain =  $10^6$ , efficiency = 20-50%, rapid response, UV-IR range, more compact, single photon counting.

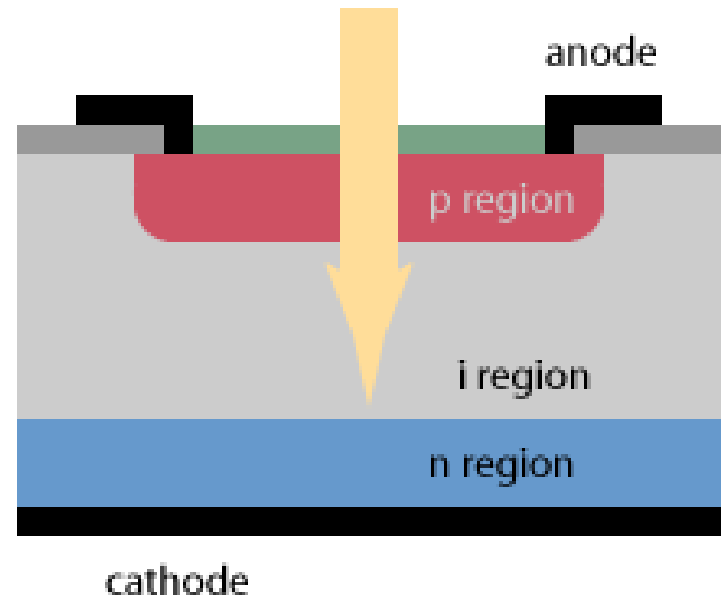
# Components of Optical Instruments

## Silicon Diode Transducers

p-i-n photodiode has a thicker depletion region to allow for more efficient collection of carriers and higher quantum efficiency.

Example: p-i-n photodiodes operating at 1.55  $\mu\text{m}$  made of  $\text{In}_{0.53}\text{Ga}_{0.47}\text{As}$  deposited on InP substrate.

Noise in a p-i-n photodiode (or p-n) is primarily due to shot noise; the random nature of the generation of carriers in the photodiode yields also a random current fluctuation.



# Components of Optical Instruments

## Multichannel Photon Transducers

Consist of an array of small photoelectric-sensitive elements arranged in a pattern on a chip.

Three types:

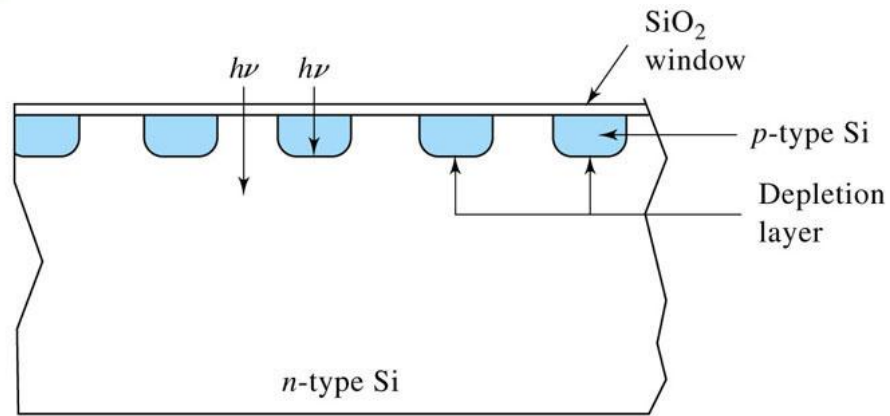
- Photodiode arrays (PDAs)
- Charge-injection devices (CIDs)
- Charge-coupled devices (CCDs)

# Components of Optical Instruments

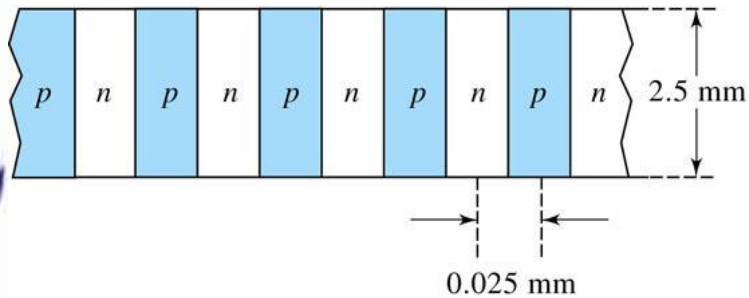
## Photodiode Arrays (PDAs)

**Small silicon photodiodes which contain reverse-biased pn junctions.**  
**Number on a chip ~ 64 to 4096.**  
**Not as sensitive as PMTs.**  
**Less dynamic range than PMTs.**

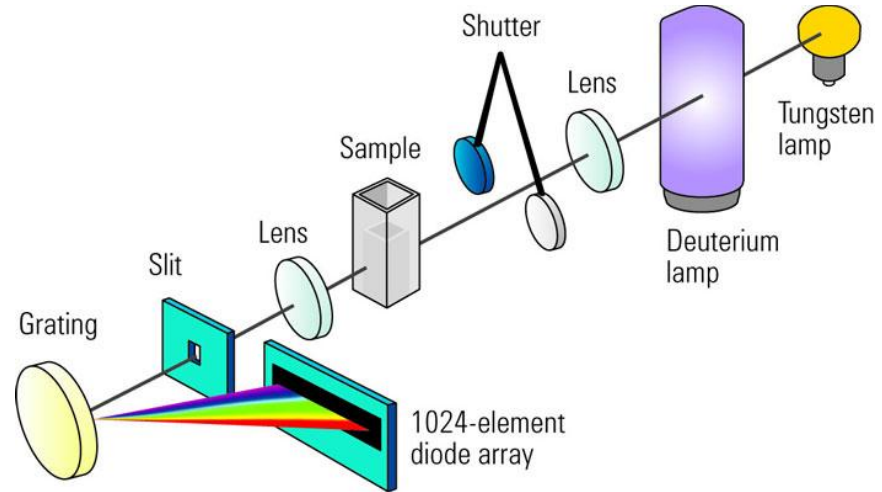
# Components of Optical Instruments



(a)



(b)



# Components of Optical Instruments

## Photodiode Arrays (PDAs)

### Advantages

**Simultaneous Multiwavelength Measurement**

**Fast Scan Speed**

**High Signal to Noise Ratio**

**Wavelength Precision**

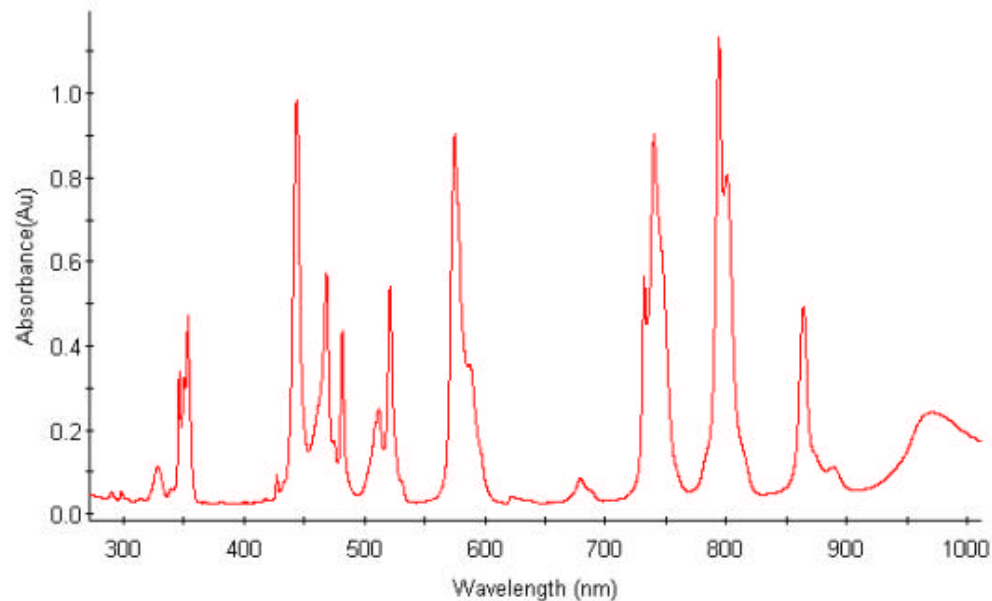
**Minimal Stray Light effects**

**Ruggedness**

# Components of Optical Instruments

## Photodiode Arrays (PDAs)

### Simultaneous Multi wavelength Measurement



The spectrum of didymium solution: S-3150, SCINCO, measuring time 1 sec.

# Components of Optical Instruments

## Photon Transducers

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# Components of Optical Instruments

## Charge-Transfer Devices CTDs (CIDs and CCDs)

- Performance closer to PMTs
- Additional advantage – can do multichannel measurements
- Can record 2-D spectrum from an echelle spectrometer

# Components of Optical Instruments

## Charge-Transfer Devices CTDs

Amount of charge generated from a radiation strike can be measured by 2 ways:

**CIDs** - the voltage change that arises from movement of the charge from under one electrode to another is measured.

**CCDs** – the charge is moved to a charge-sensing amplifier for measurement.

# Components of Optical Instruments

## Charge-Coupled Devices (CCDs)

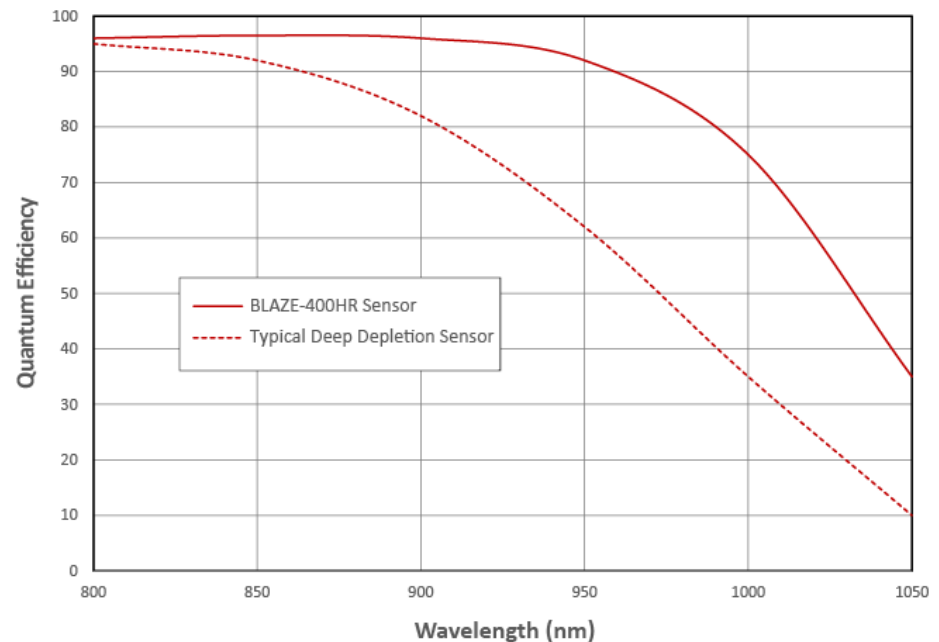
Typical array 512 x 320 pixels

- Semiconductor is formed from p-type silicon capacitor
- Capacitor is positively biased
- Electrons formed by the absorption of radiation collected in a well below the electrode
- Charges are collected at a preamplifier

# Components of Optical Instruments

## Charge-Coupled Devices (CCDs)

Linear CCD arrays and cameras are available with pixels as great as 12,000 to give very high resolution.

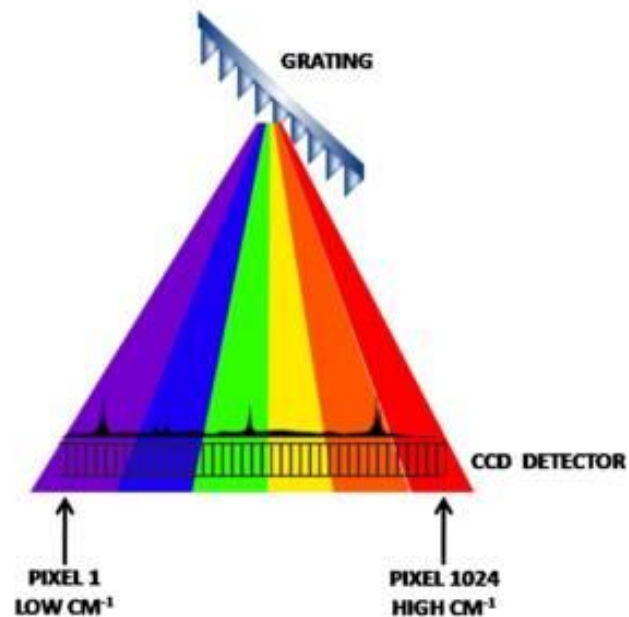


# Components of Optical Instruments

## Charge-Coupled Devices (CCDs)

Scattered light is dispersed using the diffraction grating, and this dispersed light is then projected onto the long axis of the CCD array.

The first element will detect light from the low  $\text{cm}^{-1}$  edge of the spectrum, the second element will detect light from the next spectral position, and so on...



# Components of Optical Instruments

## Charge-Coupled Devices (CCDs)

CCDs require some degree of cooling to make them suitable for high grade spectroscopy.

Typically this is done using either peltier cooling (suitable for temperatures down to  $-90^{\circ}\text{C}$ ), or liquid nitrogen cryogenic cooling.

The Peltier effect is used in detectors for cooling.

One of three reversible thermoelectric phenomena, often known simply as thermoelectric effects.

The other two are the Seebeck effect and the Thomson effect.

# Components of Optical Instruments

## Charge-Coupled Devices (CCDs)

The Peltier effect is a creation of a heat difference from an electric voltage.

This effect was observed in 1834 by Jean Peltier.

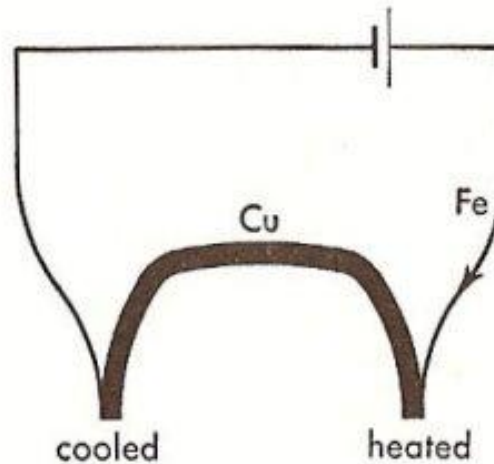
Peltier found that the junctions of dissimilar metals were heated or cooled, depending upon the direction in which an electrical current passed through them.

# Components of Optical Instruments

## Peltier effect

Heat generated by current flowing in one direction was absorbed if the current was reversed.

The Peltier effect is found to be proportional to the first power of the current, not to its square, as is the irreversible generation of heat caused by resistance throughout the circuit.



# Components of Optical Instruments

## Peltier effect

The Peltier effect can also occur when a current is passed through two dissimilar semiconductors (n-type and p-type) that are connected to each other at two junctions (Peltier junctions).

The current drives a transfer of heat from one junction to the other: one junction cools off while the other heats up; as a result, the effect is often used for thermoelectric cooling.

An interesting consequence of this effect is that the direction of heat transfer is controlled by the polarity of the current; reversing the polarity will change the direction of transfer and thus the sign of the heat absorbed/evolved.

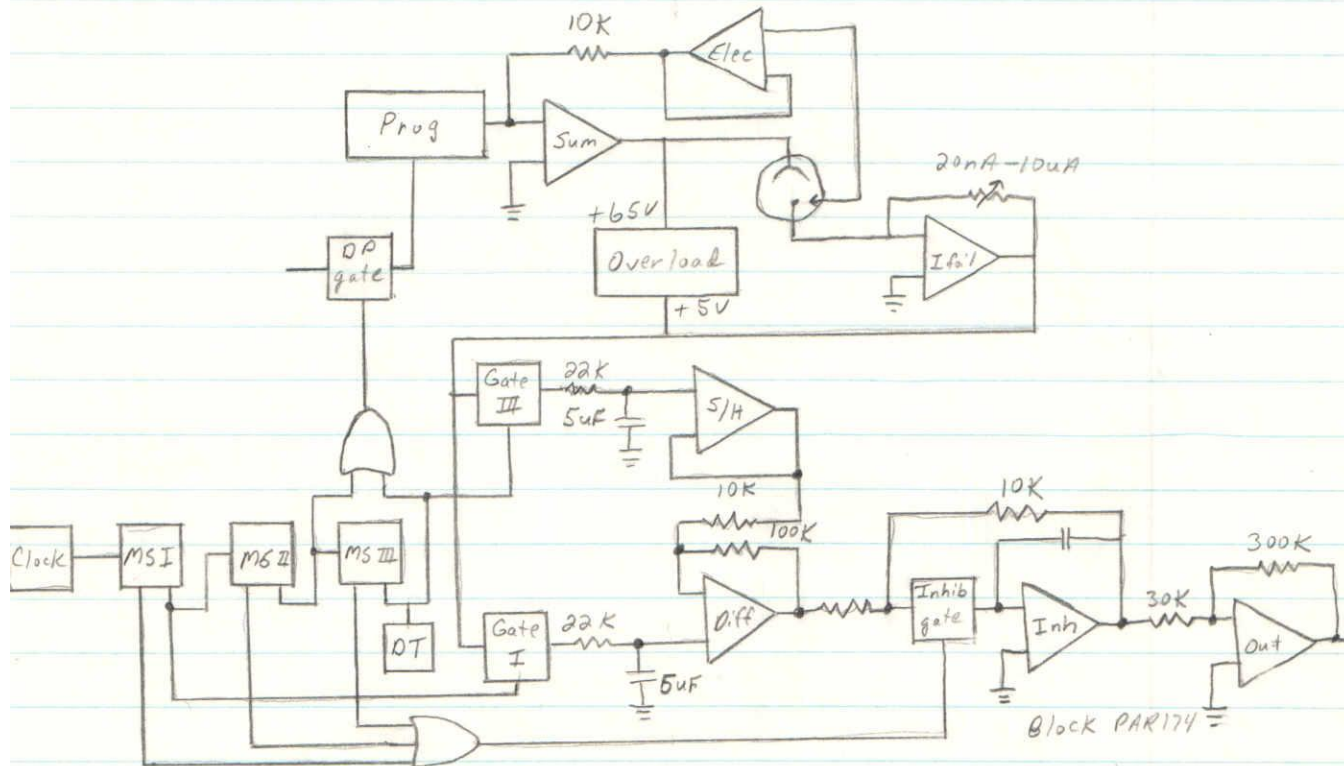
A Peltier cooler/heater or thermoelectric heat pump is a solid-state active heat pump which transfers heat from one side of the device to the other. Peltier coolers are also called thermo-electric coolers (TEC).

# Assignment

- Read Chapter 7
- Read Chapter 13
- HW4 Chapter 13: 1, 2, 5-8, 12, 13, 16-19
- HW4 Chapter 13 Due 2-6
- Exam 1- Lectures 1 to 8 - Friday Feb 9<sup>th</sup>

# Instrument Lab

Block diagram of EG+G PARC Model 174A  
Polorographic Analyzer (Instrumental Method  
of Analysis, 6<sup>th</sup> Ed, Dean & Settle)



# Instrument Lab

## II. Instrumentation

The Instrument used was a Spectrophotometer Beckman Double Beam # 14011100834. And the light source was a Beckman Hydrogen Lamp Power Supply # 337997.

Schematic drawing: Figure 1: Double Beam Spectrometer

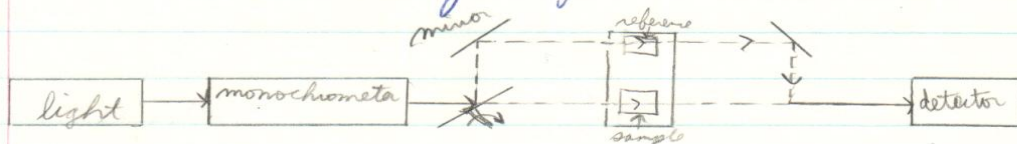


Figure 2: A scanning double-beam spectrometer with dual source, single grating.  
pg. 57, Instrumental Analysis, Dean & Settle

