



# IMAGE RECEPTORS

## 1. Screen-film mammography

- ❑ Single back intensifying screens used with single emulsion radiographic film enclosed in a light-proof cassette
- ❑ High resolution fluorescent intensifying screen
  - Absorbs X rays
  - Converts the pattern of X rays into an optical image
- ❑ Two sizes of film typically available
  - 18 cm x 24 cm and 24 cm x 30 cm
- ❑ Customary to use the smallest possible size which ensures complete coverage of the breast
  - Superior breast positioning and compression
- ❑ Women with large breasts, may require multiple films to image the breast fully

# IMAGE RECEPTORS

- ❑ Screen-film mammography
- ❑ Digital mammography
  - Area detectors
    - Indirect detectors
    - Direct detectors
    - Photo-stimulable phosphors (computed radiography or CR)
  - Scanning detectors
  - Photon counting detectors

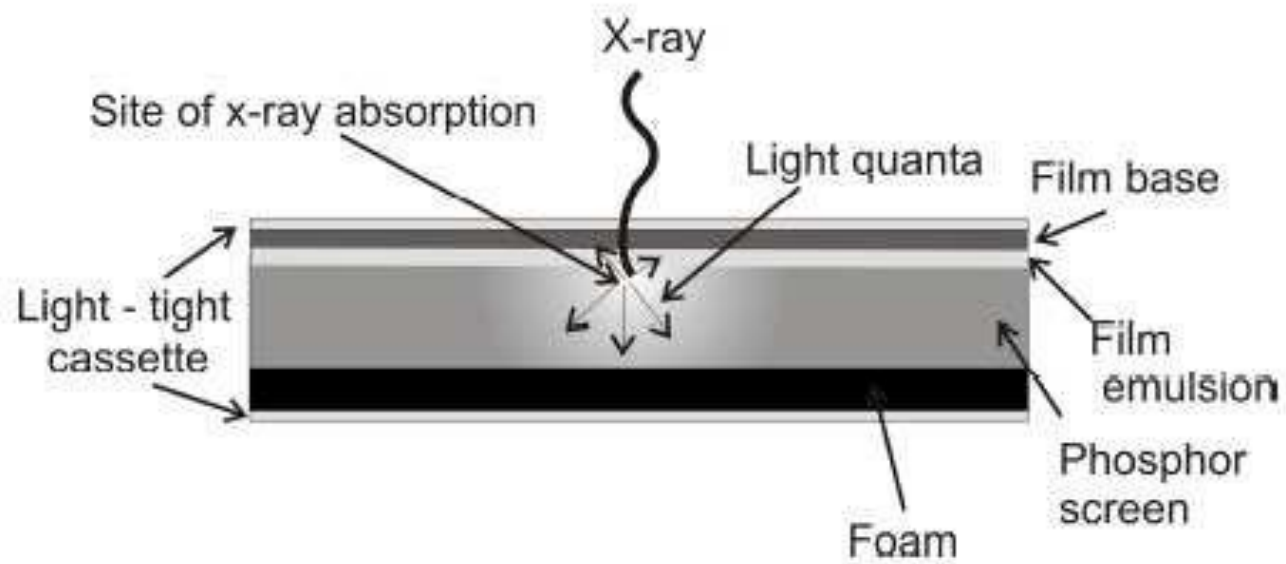
# IMAGE RECEPTORS

## 1. Screen-film mammography

- ❑ Screen and film are arranged in the cassette as shown (next slide)
- ❑ X rays must pass through cover of the cassette and the film to impinge upon the screen
  - As absorption is exponential, a larger fraction of the X rays are absorbed and converted to light near the entrance surface of the screen
  - By minimizing the distance that the light must travel before being collected by the film, blurring due to lateral spreading is reduced
  - Spatial resolution is improved
  - To further discriminate against light quanta travelling along long oblique paths, the phosphor material may be treated with a dye which absorbs much of this light, giving rise to a sharper image

# IMAGE RECEPTORS

## 1. Screen-film mammography



*Configuration for a mammographic screen-film image receptor. A single-emulsion radiographic film is held in close contact with a fluorescent screen in a light-proof cassette.*

# IMAGE RECEPTORS

## 1. Screen-film mammography

- ❑ Typical phosphor used for screen-film mammography is **gadolinium oxysulphide** ( $\text{Gd}_2\text{O}_2\text{S:Tb}$ )
- ❑ Phosphor material is dense
  - Quantum detection efficiency (fraction of incident X rays which interact with the screen) is reasonably high
    - Approximately 60% for a typical screen thickness and X rays spectrum
- ❑ Conversion efficiency (fraction of absorbed X ray energy converted to light) exceeds 10% (high for a phosphor)
- ❑ Photographic film emulsion for mammography is matched to be sensitive to:
  - Spectrum of light emitted from the particular phosphor screen
  - Range of X ray fluence exiting the breast

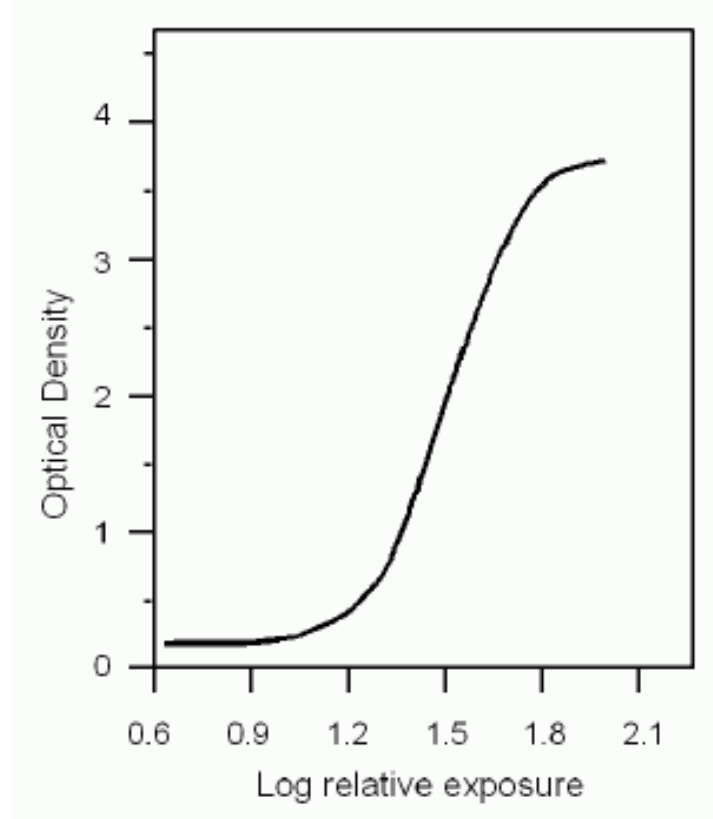
# IMAGE RECEPTORS

## 4.1. Screen-film mammography

- ❑ Important to examine the overall characteristics of the screen and film combination rather than those of the individual components
- ❑ Compression of the breast reduces overall range of X ray fluence exiting the breast
  - Allows films with high gradient to be used
  - Enhances contrast between subtly varying soft-tissue structures
- ❑ In addition, mammography film has a high  $D_{\max}$  (4.0 to 4.8 OD)
  - Maximizes exposure latitude over which the high gradient exists
  - Important near the periphery of the breast (skin edge) where its thickness decreases rapidly
  - Nevertheless, some regions of the mammogram will generally be under or overexposed, i.e. rendered with sub-optimal contrast.

# IMAGE RECEPTORS

## 1. Screen-film mammography



*Characteristic curve of a film emulsion used for mammography.*



# IMAGE RECEPTORS

## 1. Screen-film mammography

- ❑ Mammography film is processed in an **automatic processor** similar to that used for general radiography
- ❑ Important that the development temperature, time and rate of replenishment of the developer chemistry are compatible with the type of film emulsion used and are designed to maintain good contrast of the film
- ❑ **Daily quality assurance is required in mammography** to ensure on-going optimal performance
- ❑ In **screen-film mammography**, the film must act as the **image acquisition detector as well as a storage and display device**

# IMAGE RECEPTORS

## 1. Screen-film mammography

- ❑ Several factors associated with screen-film mammography can limit the ability to display the finest or most subtle details
- ❑ Sigmoidal shape of the characteristic curve results in limited latitude (range of X ray exposures over which the film display gradient is significant)
  - If a tumour is located in a more lucent or more opaque region of the breast, contrast displayed may be inadequate due to limited gradient of the film
  - Particularly of concern in patients whose breasts contain large amounts of fibroglandular tissue (dense breasts)
- ❑ Effect of fixed pattern noise due to the granularity of the phosphor screen and film emulsion
  - Can impair the detectability of microcalcifications and other fine structures

# IMAGE RECEPTORS

## 2. Digital mammography

- ❑ Digital mammography introduced commercially in 2000
  - Able to overcome many of the technical limitations of screen-film mammography
- ❑ In digital mammography, **image acquisition, processing, display, and storage are performed independently**, allowing **optimisation** of each
- ❑ Acquisition performed with low-noise X ray detectors with wide dynamic range
- ❑ As the image is stored digitally:
  - It can be displayed with contrast independent of the detector properties
  - Image processing techniques that are found to be useful can be applied prior to image display

# IMAGE RECEPTORS

## 2. Digital mammography

- ❑ Challenges in creating a digital mammography system with improved performance are mainly related to the X ray detector and the display device.
- ❑ The detector should have the following characteristics:
  - Efficient absorption of the incident radiation beam
  - Linear or logarithmic response over a wide range of incident radiation intensity
  - Low intrinsic noise and little-to-no fixed-pattern noise to ensure that images are X ray quantum noise limited
  - Limiting spatial resolution of the order of 5 to 10 cycles/mm (50 to 100  $\mu\text{m}$  sampling)
  - Can provide at least an 18x24 cm and preferably a 24x30 cm field size
  - Can image immediately adjacent to the chest wall

# IMAGE RECEPTORS

## 2. Digital mammography

- ❑ Two main approaches in detector development
- ❑ Area detectors
  - Entire image is acquired simultaneously
  - Fast image acquisition
  - Can be used with conventional design of mammography X ray unit equipped with a grid to reduce scatter
- ❑ Scanning detectors
  - Image is obtained by scanning the X ray beam and detector across the breast
  - Mechanically complex and longer acquisition times
  - Use relatively simple detector(s)
  - Good intrinsic scatter rejection

# IMAGE RECEPTORS

## 2. Digital mammography

- Typical area detectors are based of an amorphous silicon thin-film transistor (TFT) panel
  - Contains a rectangular matrix of 2000 to 3000 columns by 3000 to 4000 rows of detector elements (dels)
  - Each del is connected to electrical lines running along each row and column by a TFT switch
  - This array is covered by a phosphor or a photoconductor X ray detector

# IMAGE RECEPTORS

## 2. Digital mammography

- ❑ In “indirect” detectors each del includes both a light- sensitive photodiode and a TFT switch
- ❑ The array is covered with a **phosphor layer**
  - Typically thallium-activated **CsI**
- ❑ X rays transmitted by the breast are absorbed by the phosphor and light produced is converted in the photodiode to charge which is stored in its capacitance
- ❑ After the X ray exposure
  - Readout signals sent sequentially along the lines for each row activate corresponding switches
  - The charge is transferred down the columns to readout amplifiers and multiplexers and digitized to form the image

# IMAGE RECEPTORS

## 2. Digital mammography

- ❑ This readout system allows the signals from all of the del's to be read in a fraction of a second
  - Fast image display
- ❑ The needle-like phosphor crystals of **CsI** behave somewhat like fibre-optics
  - Conduct the light to the photodiodes with less lateral spread than would occur with granular phosphors
  - Allows the thickness of the phosphor to be increased relative to a granular phosphor to improve the quantum detection efficiency of the detector without excessive loss of spatial resolution



# IMAGE RECEPTORS

## 2. Digital mammography

- ❑ In “direct” detectors a similar readout strategy is used but the phosphor is replaced with an X ray absorber composed of **amorphous selenium** which is a photoconductor
- ❑ The energy of the absorbed X rays causes the liberation of electron-hole pairs in the selenium
- ❑ The charged particles are drawn to the opposite faces of the detector by an externally applied electric field
- ❑ To collect the signal an array of electrode pads (rather than photodiodes) forms the delts
- ❑ Unlike the phosphor-based detectors, the electric field can be tailored to collect the charge with minimal lateral spread

# IMAGE RECEPTORS

## 2. Digital mammography

- ❑ This allows the use of a relatively thick detector to achieve excellent quantum detection efficiency without significant reduction in resolution at near normal incidence
- ❑ Other materials in which X ray energy is directly converted to charge are under development
- ❑ These materials include:
  - Lead iodide, zinc cadmium telluride and thallium bromide
  - The higher atomic number of these materials allow the thickness of the X ray converter to be reduced
  - This can mitigate against the degradation of the MTF due to the oblique incidence of the X rays

# IMAGE RECEPTORS

## 2. Digital mammography

- ❑ **Computed radiography** (CR) systems can be used for mammography
- ❑ Employs a **photo-stimulable phosphor** (PSP) plate housed in a light-proof cassette
  - When exposed to X rays, electrons in the crystalline material are excited and subsequently captured by traps in the phosphor
  - After exposure the plate is placed in a reader device and scanned with a laser beam
  - The energy of the laser light stimulates the traps to release the electrons
  - The transition of these electrons through energy levels in the phosphor crystal results in the emission of light
  - The light is collected by a photomultiplier tube, the signal digitised and attributed to a particular pixel in the image

# IMAGE RECEPTORS

## 2. Digital mammography

- ❑ For Mammography CR systems the resolution of the image is determined by:
  - Size of the scanning laser beam
  - Underlying scatter of the readout laser light in the phosphor
  - Distance between sample measurements

# IMAGE RECEPTORS

## 2. Digital mammography

- ❑ Mammography CR systems differ from the general radiography CR systems in several key areas
  - Mammography CR system is designed for higher spatial resolution
  - Uses a thinner phosphor material and is scanned with finer sampling pitch (typically 50  $\mu\text{m}$ )
- ❑ However, the result is less signal per pixel
- ❑ To overcome this limitation various innovations have been developed to improve light coupling and reduce readout noise, including:
  - Dual-sided readout of the phosphor plates
  - Needle-like phosphors which permit the use of thicker detectors having superior quantum detection efficiency

# IMAGE RECEPTORS

## 2. Digital mammography

- ❑ Detector systems discussed so far acquire the image by integrating the signal from a number of X ray quanta absorbed in the detector and digitizing this signal
- ❑ The image noise from these systems depends on:
  - Poisson X ray quantum fluctuations associated with X ray absorption
  - Additional noise sources associated with the production of the converted electronic signal
  - These noise sources can arise from:
    - Fluctuation in the amount of light produced in a phosphor in response to absorption of an X ray of a particular energy or from the X ray spectrum itself
- ❑ As an alternative it is possible to **count the number of interacting quanta directly**, thereby avoiding these additional noise sources

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## 2. Digital mammography

- ❑ Typically **quantum-counting detectors** employ a geometry in which the X ray beam is collimated into a slot or multi-slit format and scanned across the breast to acquire the image
- ❑ The detector can be based on:
  - Solid-state approach (electron-hole pairs are produced in a material such as crystalline silicon)
  - Pressurized gas (the signal is in the form of ions formed in the gas)
  - Collection of charge signal plus amplification produces a pulse for each interacting X ray quantum and pulses are counted to create the signal
- ❑ As the beam is collimated to irradiate only part of the breast at a time the system has:
  - Good intrinsic scatter rejection without the need for a grid
  - Increased dose efficiency