Industrial Applications of Accelerators: Traditional and new

Accelerators for America’s Future
Washington, October 26th 2009

Yves Jongen
Founder & CRO
Ion Beam Applications sa
Generally, high energy particle beams induce nuclear reactions and activation.

In contrast, in industrial applications, nuclear reactions and activation are undesirable and avoided, but other effects of ionizing radiations are researched.

These desired effects include:
- Sterilization
- Cross linking of polymers
- Curing of composite materials
- Modification of crystals
- Doping of semi conductors
- Beam aided chemical reactions
- Thermal or mechanical effects of the particle beam
Which beams are used?

- The choice of particle beams used in industrial application is defined, to a large extent, by the desire to avoid nuclear reactions and activation.

- Commonly used beams include:
  - Electron beams below 10 MeV
  - X-Rays from e-beams below 7.5 MeV
  - Intense, low energy proton beams
  - Heavy ion beams well below the Coulomb barrier

- Also, for industrial applications, large beam currents/powers are needed to reach industrial scale production rates. Beam powers from 50 kW to 1 MW are common.
Key E-beam and X-ray Industrial Applications

- Sterilization
  - Sterilization of Medical Devices
  - Surface Sterilization
  - Food Pasteurization

- E-beam induced chemistry
  - Reticulation of Polymers
  - Curing of composites
  - Environment remediation

- E-Beam induced crystal defects
  - Modification of Semiconductors
  - Coloring of Gemstones
High power E-beam accelerators: 1) the Dynamitron
High power E-beam accelerators: 2) the Linacs

On-Site is a complete turn key operating system validated to ISO 11137 and delivered with all required training, documentation, dosimetry system and process certification.
High power E-beam accelerators: 3) the Rhodotron
The options for the sterilization of medical devices

- Steam (incompatible with most polymers)
- Ethylene Oxyde
  - Inexpensive
  - EtO is explosive, toxic and harmful to the environment
  - EtO sterilization may leave harmful residues
- Irradiation
  - Cobalt
  - E-beam
  - X-ray
The options for sterilization by irradiation

**E-beam**
- Accelerator: Up to 10 MeV
- Electron source
- Scanning Magnet
- Scan Horn
- Window
- E-Beam

**X-ray**
- Accelerator: Up to 7.5 MeV
- Electron source
- Scanning Magnet
- Scan Horn
- Window
- X-rays
- Electron – X-Ray Converter

**Gamma**
- Cobalt 60

Gamma Rays
- Gamma Rays
Depth-Dose Distributions – EB and X-ray

- 10 MeV electrons
- 5.0 MeV X-rays
- 7.5 MeV X-rays
The options for sterilization by irradiation (1)

- **Gammas from Co60**
  - Low investment cost, specially for low capacities
  - Simple and reliable, scalable from 100 kCuries to 6 MCuries
  - Isotropic radiation > inefficiencies in use
  - Pallet irradiation, but low dose rate > slow process
  - Absolutely no activation
  - Cannot be turned OFF > inefficient if not used 24/7
  - Growing security concern: the cobalt from a sterilization plant could be used to make dirty bombs

- **Electron beams**
  - Directed radiation > Efficient use
  - Lowest cost of sterilization for large capacities
  - Can be turned OFF > safer
  - Short range (4.5 g/cm² at 10 MeV) > 2-sided irradiation of boxes
  - More complex dose mapping
  - Minimal, hardly measurable, but non zero activation
The options for sterilization by irradiation (2)

- X-Rays from E-beams
  - Excellent penetration
  - Simple dose mapping
  - Pallet irradiation
  - Directed radiation > Efficient use
  - Loss of a factor 10 in energy when converting e-beams to photons
  - Cost of sterilization higher than electrons
  - Cost of sterilization is generally higher by X-Rays than Cobalt if used 24/7, excepted for very large capacities
  - Can be turned OFF > safer
  - Minimal, hardly measurable, but non zero activation
E-Beam medical disposables facility
700 kW Rhodotron with 3m long X-Ray target
X-ray facility layout
Food irradiation applications

- **Low Dose Applications (< 1kGy)**
  - **Phytosanitary** Insect Disinfection for grains, papayas, mangoes, avocados...
  - **Sprouting Inhibition** for potatoes, onions, garlic...
  - **Delaying of Maturation**, parasite disinfection.

- **Medium Dose Applications (1 – 10 kGy)**
  - **Control of Foodborne Pathogens** for beef, eggs, flounder-crab-meat, oysters...
  - **Shelf-life Extension** for chicken and pork, low fat fish, strawberries, carrots, mushrooms, papayas...
  - **Spice Irradiation**

- **High Dose Applications (> 10 kGy)**
  - **Food sterilization** of meat, poultry and some seafood is typically required for hospitalized patients or astronauts.
Surface Treatment of Carcasses

Relatively low voltage e-beam

1 to 3 cm treatment depth

Mitigates risk of e-coli entering processing plant.

May be exempt from labeling requirements
E-beam induced chemistry
E beam treatment of Tires

- Reduction in material hence in the weight of the tire
- Relatively low cost synthetic rubber can be used instead of costly natural rubber without a loss in strength
- The radiation pre-vulcanization of body ply is achieved by simply passing the body ply sheet under the scan horn of an electron accelerator to expose the sheet to high-energy electrons
- Higher production rates
- Construction of green tires
- Reduction of production defects
Polymer Cross-Linking

- **Wires** stand higher temperature after irradiation
- **Pipes** for central heating and plumbing
- **Heatshrink elastomers** are given a memory
Composite curing: X-ray Cured Carbon Fiber

- Sports Car Fender made light, resistant and requiring less fuel
Production of High Heat Resistant SiC fibers

Advanced Materials Development / Ceramic Composites

SiC Fiber
- Diameter: 14μm
- Tensile strength: 3GPa (300kg/mm²)
- Heat resistant: 1700°C
- Density: 2.7g/cm³

SiC fiber (Hi-Nicalon®)

EB irradiation up to 10MGy
Cured polymer fiber
Pyrolysis in inert gas (~1500°C)

Application

Ceramic Matrix Composites
Space plane materials

© 2006
E-beam applications for the environment

- Flue gas treatment
- Liquid effluents treatment
- Production of Viscose
EB Based Flue Gas Cleaning

- Removal of SOx and NOx
- Pilot Plants: China, Poland, Japan, USA, Malaysia, Germany
- Coal Power Plants & Municipal Waste Incinerators
E-beam induced defects in crystals
Gemstones

Improving the color of glass and gemstones
E-beam irradiation improves SC switching speed

Typical semiconductors:

- fast recovery diodes
- power diodes
- Bipolar power transistors
- power MOSFETs
- power rectifiers
- IGBT’s
- thyristors
- silicon-controlled rectifiers
Industrial use of low energy proton beams
Blistering caused by 300 keV protons on copper
Industrial application of the Bragg Peak
The present process using wire saws

Mono Si
- Growing/Casting
- Cropping
- Squaring/Bricking

Poly Si

Steps:
1. Edge grinding
2. Gluing
3. Wafer Cutting
4. Wafer Separating
5. Wafer Cleaning
6. Wafer Measuring
Sigen « Direct Cleave » AKA « Beam Saw » process

- Two Step Process
  1. Implant 2…4 MeV protons (20 mA)
  2. Cleave

- Eliminates Kerf Loss
- Eliminates Consumables
  - SiC, Slurry, Wire
- Eliminates Other Systems
  - Gluing
  - Singulation
  - Cleaning
  - Less Damage Etch
SEMS of the as-cleaved edge
Industrial silicon cleaving equipment “Dynasolar”
Industrial use of low energy heavy ion beams
Ion implanters are used for the doping of SC
Microfiltration membranes by heavy ions

- Heavy ion beams are used to produce track-etched microfiltration membranes, commercialized i.a. under the brand name “Cyclopore”
- In these membranes, tracks of slow, heavy ions crossing a sheet of polymer are chemically etched, giving cylindrical pores of very accurate diameter
Thank you!