Solid State Nuclear Track Detectors (SSNTD)

Jonathan Monson
Experimental Methods in High Energy Physics
December 13, 2013
Table of Contents

1. Introduction
2. The basic principles of SSNTD technique
3. Types of SSNTD
4. Physics and Chemistry of Nuclear Tracks
5. Measurements
6. Applications
Introduction

- SSNTDs have become a popular and well established method of measurement in a large number of fields:
  - Fission and nuclear physics
  - Astrophysics physics
  - The study of meteoritic and lunar samples
  - Cosmic rays
  - Particle accelerators and reactors
  - Archeology
  - Medical Physics
  - Dosimetry
  - Biology
Introduction

Reason why it is so popular:

- Simplicity of use
- Low cost of its materials
- Versatility of its possible applications
- Small geometry of the detectors
- Ability to preserve their track record for a long time
- They do not need any electronic/electric
- Low maintenance
- Can be fine tuned, through doping, to detect certain particles, or energy ranges
Basic Principles

- Heavy ionizing particle (proton, alpha, fission fragment, etc.) passes through the SSNTD

- Breaks up molecules creating a damaged trail.

- The size of this damage trail is proportional to the linear energy transfer (LET) of the particle.
  - LET is the amount of energy transferred from the ionizing particle to the material.

The formation of a particle track in a polymer (from Fleischer et al.)
Basic Principles

- These damaged trails, also known as tracks, can be observed either directly by
  - Transmission electron microscope (TEM)
  - Optical microscope
    - Through the process of etching

- Etching:
  - SSNTD are placed in a strong acid or base solution
  - The solution will attack the latent damage trail at a much faster rate than that of the bulk material causing the formation of conical pit.
  - These conical pits look like circles or ellipses under a microscope.

As chemical etching progresses, the latent damage trail is etched preferentially and a track cone is formed on the surface of the detector.
Types of SSNTD

Inorganic Solids (Crystals and Glasses)
- Phlogopite mica
- Muscovite mica
- Silica glass
- Flint glass

Application in:
- Geology
- Planetary sciences
  - lunar
  - meteoritic samples
- Oil exploration
- etc.

Organic Solids (Polymers)
- Polyethylene terephthalate
  - (Cronar, Melinex)
- Bisphenol A-polycarbonate
  - (Lexan, Makrofol)
- Polymethylmethacrylate
  - (Plexiglas, Lucite, Perspex)
- Cellulose triacetate
  - (Cellit, Triafol-T, Kodacel)
- Polyallyldiglycol carbonate
  - (CR-39)

Application in:
- Radiation monitoring
- Radiation measurement
- Nuclear physics
- Radioactivity
- etc.
Types of SSNTD

- The most widely used SSNTDs today are plastic
  - Do not require special preparation
    - Grinding and polishing.
  - Much more sensitive
- CR-39 polymer
  - (polyallyldiglycol carbonate: $\text{C}_{12}\text{H}_{18}\text{O}_7$).
  - Most Sensitive
  - Widely used
  - It can record all charged nucleons, starting with protons.
Physics and Chemistry of Nuclear Tracks

- A fast-moving charged particle loses energy by excitation and ionization
- Creates charged centers in material
- Ejected electrons ($\delta$-rays) can produce further excitation and ionization
Physics and Chemistry of Nuclear Tracks

- **Etching Procedures:**
  - Usually carried out by Sodium Hydroxide NaOH
  - Higher temperatures
    - About 30-90 °C
  - Different amounts of time:
    - Shorter time for low LET particles
    - Longer time for High LET particles
Physics and Chemistry of Nuclear Tracks

Particle Trajectory

Pre-etch surface

Target fragment interaction

Post-etch surface

Target fragment interaction

Particle stopping point

Particle Trajectory

(a) (b) (c) (d)
Physics and Chemistry of Nuclear Tracks

- **Electrochemical Etching**
  - SSNTD is pre-etched
  - Slowly moved between high-voltage electrodes
  - Spark is formed when the etched hole is passed between the electrode

![Diagram of Electrochemical Etching Stages](image-url)
Measurements
Measurements

- **Manual counting**
  - Optical microscope
  - Moving stage
  - Two eye pieces
  - Computer and Monitor
  - High degree of counting precision

- **Automatic counting**
  - 98% accurate with heavy particles (C and higher, fission fragments)
  - No standard way of doing it (to each their own)
  - Not as accurate
Measurements

- Non-etched tracks in polymers
  - 10 – 100 nm
- Chemically etched tracks
  - 1 μm
- Electro chemical etached tracks
  - 100 μm
Applications:
(Neutron Measurements)

- Neutrons cannot produce etchable tracks directly
- Etchable tracks are caused by proton recoil
  - Elastic n(p,p)n reactions.
  - Can have fission fragments with C and O
- 6LiF can be placed in contact with CR-39
  - High neutron cross section
  - Measure the neutron fluence by counting the number of alpha particles.
Applications:
(Medical Physics)

- Measuring neutrons in a medical linear accelerator
  - As high energy, (>10MV), x-rays can interact with high dense materials, producing neutrons
- CR-39 detectors are insensitive to x-rays
  - They make an ideal detector
Applications:
(Dosimetry)

- Among topics related to the application of SSNTDs in radiation protection are:
  - Radon dosimetry
    - in homes, workplaces, mines
  - Neutron dosimetry
    - around nuclear or accelerator facilities
  - Heavy ion dosimetry
    - space missions, supersonic air travel, personnel dosimetry of regular crew members of high-altitude aircraft.
Applications:
(Planetary Science)

Lunar Samples

• In the early 1970s, the SSNTD technique helped scientists understand the radiation history of the moon.

• Moon was a near-perfect vacuum
  • low-energy cosmic rays had been able to reach the surface of the moon.
Applications:
(Meteoritic Samples)

- Age determination
- Cooling-down of the early solar system
- Determination of pre-atmospheric size of meteorites
- Cosmic Ray Measurements: Particle Identification
FIGURE 3.12 Photograph of a 3D model of the track of a cosmic ray slowing down in a stack of six plastic sheets. Note that the rate of change of the etched cone length with distance, in a given medium, is a unique function of the atomic number and mass of the cosmic ray particle. The length of the etched cone increases from top to bottom through sheets 1, 2, 3, 4, 5 as the velocity of the particle decreases, until finally it stops in sheet 6 (The model was made by the group headed by W. Enge at Kiel University, Germany).
Reference