Production of thin, self-supporting $^{28}\text{Si}$ foils for near barrier fusion experiments with radioactive beams

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Isotopically-pure, thin target-foils are an essential part of nuclear experimentation in the era of radioactive beams
Motivation

- Prior experiment: $^{39,47}K + ^{28}Si \rightarrow ^{67,75}As^*$
- $^{28}Si$ targets produced at Legnaro National Laboratory, INFN, Italy
  - Total thickness $\approx 400 \mu g/cm^2$
  - $^{28}Si$ with oxygen content $\approx 30$
- $^{39,47}K + ^{16}O \rightarrow ^{55,63}Co^*$ - Contaminant reaction
- Presence of oxygen complicates the identification of fusion residues
- Goal: Create minimal-oxygen $^{28}Si$ targets for future experiments
Foil production through vapor deposition

• Need for a high quality electron beam evaporator system for refractory materials
  • Si melting temp = 1414°C
  • Si boiling temp = 3265°C
• Purchased Ferrotec/Temescal Model 1CK electron beam evaporator
  o 8 kW maximum power draw
  o 10 kV tight electron beam
  o Electron beam sweeps in X and Y (uniform heating)
  o 4 pocket crucible
• Evaporator cooled by HASKRIS WW2
• Deposition monitored through Telemark Model 851 Thickness Monitor (Quartz-Crystal Monitor - QCM)
Implementing an evaporation system

- Stainless steel vacuum chamber electropolished by Able Electropolishing
- Baked chamber at 130°C for 48 hours
- Oil-free pumping system:
  - Roughing vacuum ($\approx 10^{-2}$ Torr) with Edwards nXDS Scroll Pump
  - Evacuated to high vacuum
  - $10^{-2} < P < 10^{-6}$ Torr Turbopump (500 L/s)
  - $P < 10^{-6}$ Torr CTI-8 Cryopump
Implementing an evaporation system

- Evacuate to \( P \approx 5 \times 10^{-7} \) Torr prior to evaporation (typically in 24 hours)
- During evaporation \( P \approx 1 - 2 \times 10^{-6} \) Torr
- Viewports for monitoring electron beam during deposition
Foil production process

• Substrate held on heating block
  - Heated to ≈365°C
  - Block heated using single loop of 0.25 mm tungsten wire looped through ceramic tubes in copper block (I = 3.25 A, V = 16 V)

• Releasing agent: >99% BaCl₂
  - Water-soluble for floating foils
  - Pressed into 200 mg pellets (900 psi)
  - Rate ≈300 Å/s on substrate
  - Deposit ≈75 kÅ on substrate

• Si deposition:
  - Material: 99.95% natSi pieces (≈100 mg/piece, ≈3 g total)
  - Rate ≈30 Å/s on substrate
  - Deposit ≈9.5 kÅ on substrate (≈220 µg/cm²)
  - ≈85 mg total Si used per evaporation
Role of different substrates

• Tungsten substrates:
  o Tungsten previously characterized as optimal substrate
  o A.M. Sandorfi, et al., NIM 136 (1976) 395
  o Silvery, metallic appearance
  o Foils crumbled during floating
  o Electropolished to reduce surface roughness – foils still crumbled

• Copper substrates:
  o Electropolished to reduce surface roughness
  o Silvery, metallic appearance
  o Self-supporting foils
Releasing foil from substrate

- Substrate size = 1” x 3”
- Each foil cut into 3 smaller pieces
- Pieces individually floated into DI water
- Foils picked up on aluminum target frames (1.5cm diameter hole)
- Initial evaporations yielded foils which curled upon release from substrate
- Foils were annealed (24 hours @ 350°C) to reduce foil curling during floating
Preparing for $^{28}$Si evaporation

• Evaporating with a limited quantity
  o New tantalum crucibles made by IU Mechanical Instrument Services
  o Reduced natSi amount from 3g->1g
  o Reproduced previous NatSi results

• Isotopically-enriched $^{28}$Si (>99.8%, 2g) obtained from National Isotope Development Center (ORNL)

• Self-supporting $^{28}$Si foils produced and floated (with and without pinholes)

219 $\mu$g/cm$^2$ $^{28}$Si foil mounted on an aluminum target frame
Conclusion

• Summary:
  o Designed and assembled electron beam evaporation system for evaporation of refractory materials
  o Successfully evaporated and floated both $^{\text{nat}}\text{Si}$ and $^{28}\text{Si}$ foils with metallic appearance

• Future work:
  o Understand and fix pin-hole problem
  o Characterization of targets:
    o Alpha particle energy loss ($^{148}\text{Gd} \to 3.183 \text{ MeV}, \Delta E \text{ thru } 200 \text{ ug/cm}^2 = 160 \text{ keV}$)
    o Rutherford backscattering (Hope College – Dr. Paul DeYoung)
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Additional Slides
Mass measurement

• Check of QCM accuracy
• Slide weighed before and after evaporation
• No BaCl$_2$ deposited
• QCM thickness = 292.7 µg/cm$^2$
• ‘Mass’ thickness = 299.5 +/- 6 µg/cm$^2$
Electropolishing details

• Tungsten:
  o Stainless steel cathodes
  o 0.25 M NaOH
  o V = 5.0 V, I = 2.64 A
  o 15 minutes

• Copper:
  o Stainless steel Cathodes
  o 50% H₃PO₄
  o V = 5.0 V, I = 3.0 A
  o 15 minutes