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THIN-FILM CRYOGENIC ACCELERATOR TARGETS

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Thin-film accelerator targets (0.1 mg/cm^2 < ρx < 20 mg/cm^2) produced by condensation of various gases (Ar, Kr, Xe, N_2, etc.) onto thin, cryogenically cooled substrates (T = 20 K to 80 K) have been developed and tested in-beam with 35 MeV ^{4}He.

Studies of nuclear or atomic reactions involving neon, argon, krypton, xenon, fluorine, sulfur, chlorine, nitrogen, and other elements as targets have required use of gas cells, differentially pumped chambers [1], or compound solid targets (e.g. melamine). The large spatial extent of a gas cell target can cause severe geometrical problems, e.g. at small scattering angles where good angular resolution is required. Also, measurements at $\theta = 0°$ are usually not feasible. Compound solid targets often contain unsuitable elements. Many of these limitations can be minimized if the target material is condensed as a thin film onto a thin substrate using cryogenic techniques [2–4]. A short report by Fulbright [5] describes an apparatus used to condense water vapor onto thin foils for use in a nuclear reaction study [6] of ^{16,18}O(p, t).

In this note we describe tests of several thin-film cryogenic targets operating at 20 K ≤ T ≤ 80 K suitable for use in nuclear and atomic reaction studies.

The cryostat consisted of a commercial LN/LHe cryo-pump [7] modified [8] for use as an accelerator target holder (fig. 1). Provisions were made for pumping the inner cryostat with a high capacity rotary oil pump to further reduce the temperature of the inner cryostat liquid when using LN. The temperature of the LN cryostat, outer heat shield, inner cryostat, and target frame were monitored by carbon and Pt resistors. The target holder consisted of a slotted 5 mm thick, 30 × 50 mm^2 copper block (OFHC) fastened with indium gaskets (for thermal conductivity) to the inner LHe cryostat (fig. 1). The target block could be mounted at either a right angle to the beam (i.e. $\phi = 0°$) or at $\phi = 45°$. The latter permitted reflection geometry to be utilized at scattering angles greater than about 70°.

The target frame, which held the substrate foil, was also made from OFHC copper (1 mm thick) with a 10 mm diameter target opening. Substrate foils were mounted on the target frame using silver conducting paint or thermal-conducting epoxy. The choice of substrate is governed by the type of target or reaction to be studied, and by the thickness and thermal conductivity required [8–10].

The cryostat and target assembly were mounted on top of a 50 cm diameter aluminum chamber (fig. 1). The beam from the accelerator was constrained to a 2.5 mm diameter spot on the target with a graphite collimator

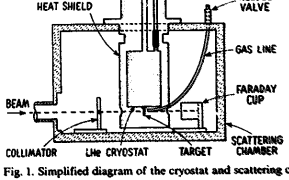

Fig. 1. Simplified diagram of the cryostat and scattering chamber (particle detectors not shown).

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placed just in front of the outer heat shield. Reaction products from nuclear scattering or reactions could be detected at selected angles ($\theta_{lab} = \pm 45°, +90°, +135°$) with suitably collimated ($\Delta\theta \approx 2°$, $d\Omega \approx 1$ msr) Si surface barrier detectors operated as total energy detectors (i.e. without particle identification) or as ΔE–E detector particle telescopes (i.e. with ion separation). The latter were used to study particle transfer reactions and also provide cleaner spectra for elastic alpha particle scattering.

The experimental technique was the following: first, a scattering spectrum was obtained from a bare substrate. The outer and inner cryostats were then cooled with LN, and pumped LN or LHe, respectively. After cool down, the target chamber vacuum was typically 10^{-7} Torr owing to cryo-pumping. The target gas was then slowly bled onto the substrate while monitoring the chamber vacuum for a slight pressure rise. The rate of target gas deposition and thickness could be conveniently monitored in-beam by observing the shape and magnitude of the elastic scattering peaks.

Typical deposition rates were 0.2 mg/cm^2 per minute. Slow depostion was required to form uniform targets, prevent excessive substrate heating, and insure that most of the gas was condensed on a single side of the substrate (as determined by the spectral line shape and visual inspection of the target). In this manner it was possible to deposit uniform, single-sided targets at any desired thickness up to several tens of mg/cm^2, i.e. several microns thick.

The target gases were deposited 0.1 to 20 mg/cm^2 thick with corresponding energy resolutions ≈ 50 keV to > 800 keV. (The resolution for light elements was limited by kinematic broadening across the 2° detector aperture.)

The maximum beam intensity that can be tolerated is a function of the thermal conductivity of the substrate, the substrate temperature, and the melting point of the target [8]. Thus Kr, Xe, NH_3, CS_2, SF_6, etc., cooled to $\lesssim 25$ K on Be, Al, Cu or Au were observed to tolerate 50–100 nA of 35 MeV α-particles while N_2 and Ar at ≈ 25 K, or Xe, etc., at ≈ 60 K (pumped LN) could tolerate only 10–20 nA before observable target degradation occured.

Elastic α particle scattering spectra for $E_\alpha = 35$ MeV are displayed in figs. 2–5 for a few of the combinations of substrates and target gases investigated [8]. Target thicknesses were inferred from the energy loss of the incident beam passing through the gas deposited on the substrate. Low mass substrates (Be, Al) proved suitable for heavier gases (Ar, Kr, Xe) while gold was useful for light elements ($A < 40$) but the optimum choice depends on the reaction to be studied.

The energy resolution obtainable in the transmission mode is limited by energy loss in the substrate, although quite thin substrates ($\rho x < 0.5$ mg/cm^2) are feasible for

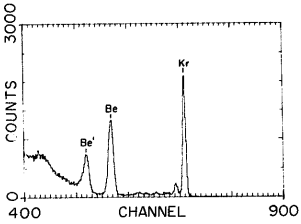

Fig. 2. An energy spectrum at $\theta = 45°$ ($\phi = 0°$, transmission mode) for 35 MeV α (particles scattered from Kr gas ($\rho x \approx 3$ mg/cm^2) deposited on a 0.9 mg/cm^2 Be substrate ($T \approx 25$ K). The spectrum includes ^{4}He, ^{3}He and other particles (i.e. no particle identification). Elastic and inelastic scattering peaks are indicated by unprimed and primed labels, respectively.

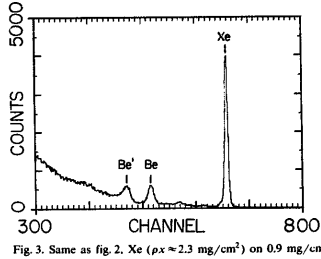

Fig. 3. Same as fig. 2, Xe ($\rho x \approx 2.3$ mg/cm^2) on 0.9 mg/cm^2 Be ($T \approx 60$ K).

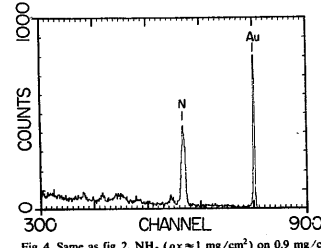

Fig. 4. Same as fig. 2, NH_3 ($\rho x \approx 1$ mg/cm^2) on 0.9 mg/cm^2 Au ($T \approx 60$ K) with particle identification set for ^{4}He.

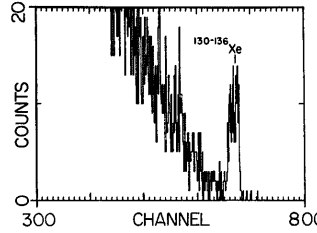

Fig. 5. Spectrum at $\theta = 90°$ ($\phi = 45°$), reflection mode for 35 MeV α particles scattered from natural Xe ($\rho x \approx 2$ mg/cm^2) on 0.9 mg/cm^2 Be ($T \approx 60$ K; no particle separation). The structure of the Xe peak is attributed to various isotopes of Xe. $A \approx 130$–136, and/or their excited states.

highly condensable gases (e.g. NH_3, SF_6, etc.) Otherwise, one can operate in the reflection mode for $\theta > 70°$, which permits high resolution work. Interference from the substrate can be minimized by choice of a low mass substrate (e.g. Be) which will be kinematically shifted to low energies, particularly for heavy ion incident beams.

A spectrum for Xe on Be at $\theta = 90°$ (reflection mode) is displayed in fig. 5. The resolution was sufficient (200 keV) to permit separation of some of the Xe isotopes. A particle telescope was used for several targets to observe (α, ^{3}He) spectra from different nuclei [8].

One of the main limitations of cryo-targets is the build up of carbon, nitrogen and oxygen contaminations owing to cryo-pumping by the target. In our tests this was aggravated by the poor quality of the cyclotron beam line vacuum (10^{-5} to 10^{-6} Torr). Most spectra (figs. 2–5) exhibited a build up of condensed vapors other than the target gas. A clean, oil- and grease-free vacuum is thus highly desirable to minimize contaminations. In addition, certain substrates, e.g. Al and Cu, exhibited signs of oxidation when left exposed to air [8]. In this respect beryllium and gold appeared to be the best substrates.

The advantages of a cryo-target system relative to a gas cell are: (a) high density, (b) well-defined geometry, (c) wide choice of substrates, (d) $\theta = 0°$ measurements feasible, and (e) reflection (i.e. windowless) mode is possible.

The disadvantages are: (a) substrate is in-beam, (b) contamination from the accelerator vacuum system, (c) beam heating limitations, and (d) gas recovery is more difficult for rare isotopes.

With proper choice of substrate and cooling apparatus (cryostat or refrigerator), thin-film cryogenic targets appear to be quite feasible for nuclear or atomic reaction studies for many types of elements not readily available as suitable solid targets.

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