Graphene Backing for Radioisotope Targets

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Outline

- Who is Applied Nanotech (ANI)?
- Prior effort using graphene
- Problem – need for radioisotope targets
- Approaches for using graphene foils to make targets – description of results
- Commercialization

About ANI

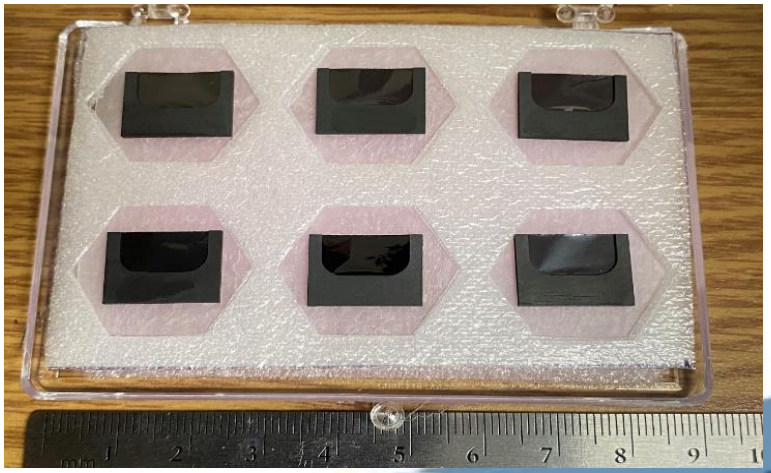
- Located in Austin, Texas
- Founded 1988, publicly traded
- In 2014, merged with Nanofilm (Cleveland, OH), both are now subsidiaries of Nano Magic Inc. (OTC:NMGX)
- Technology emphasis:
  1) Graphene foils and films
  2) Isotope Targets
  3) Printed Electronics (Ink and pastes of Cu, Ni, CuNi-alloy, Al, Ag, custom formulations)
  4) Sensors
- Nano Magic has 20+ employees, ANI has staff of 4
- ISO 9001:2015 Certified Quality Management System

Prior ANI Effort Using Graphene

- Graphene Stripper Foils for FRIB (Facility for Rare Isotope Beams).
  - DoE grant DE-SC0000852: The goal of this program was to develop a high thermal conductivity, rigid, large area, uniform carbon foil for charge stripping in accelerators, capable of having long lifetime
  - Fabricated by filtration of reduced graphene oxide (rGO). Size up to 25 cm diameter (typical 12.5 cm diameter), typical thickness 0.1 to 1.0 mg/cm^2, can be cut per order
  - Longer lifetime (up to 2x) in charge stripping applications compared to conventional vapor-deposited carbon foils

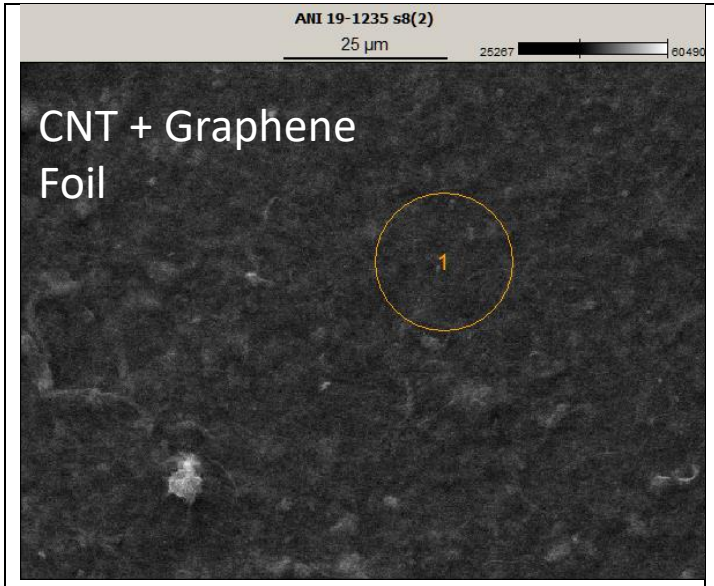
Prior ANI Effort Using Graphene

- The foils are smooth and have a metallic luster
- Foils are robust, easy to handle and survive express shipping
- Lifetimes exceeding 7,500 µA-hrs routine in GE PETtrace cyclotrons
- Can be cut to size (customer specs)
- Several foil mounting options
- Thermal conductivity measured at 1480 W/mK (laser flash method) = similar to HOPG

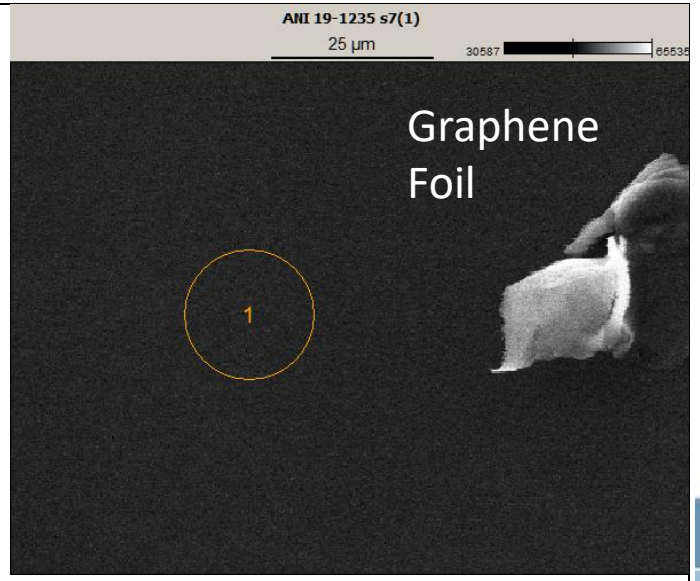


Carbon Nanotech (CNT) + Graphene Foils

- Developed new stripper foil with 50:50 mixture of CNT and graphene.
- CNT-enhanced foils:
  - Are stronger and stiffer than graphene-only foils.
  - Are rougher with higher porosity – leading to higher number of nucleation sites for plating.
  - Have a greater ability to hold nanoparticles and micropowders of target materials
  - Can layer the target with carbon-rich and target-material-rich surfaces.



SEM image of CNT-Graphene foil. CNT fiber bundles are present.



SEM image of standard graphene foils at same magnification for comparison.

Problem

A variety of thin isotope targets are needed in NP research

- Need for robust backing made of a low Z material

- Targets of interest: refractory metals, targets with limited amounts of isotopes available (mg quantities), both stable and radioactive isotopes, B-11, etc, that are difficult to make thin (0.5 -10 mg/cm^2).

- Effective, efficient methods of thin target fabrication are needed

- **This program: Graphene Backing for Radioisotope Targets**
- **DoE Grant DE-SC0017208, Phase II completed**
- **(Topic 26(e) - Specialized Targets for Nuclear Physics Research)**

Target fabrication approaches

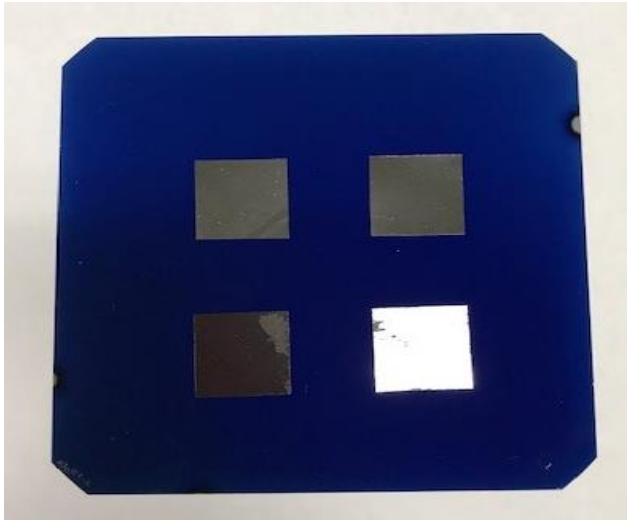
- Use thin graphene backing films for target fabrication by magnetron sputtering:
  - Demonstration – deposit enriched $^{11}B_4C$ boron carbide
- Spin-coating target material onto graphene substrates
- Use graphene foil as a cathode for electroplating of isotopes:
  - Demonstration – plated ^{nat}Cr and ^{52}Cr on graphene target
- Use graphene or CNT+graphene as a matrix for composite targets where the target material is in nanoparticle or few micron powder format. Can load 2:1 target:carbon.
  - Demonstration – Targets of rhenium, hafnium, tungsten, bismuth, chromium, boron, boron-10, iridium
  - Works as easily for metals, oxides, carbides, and other compounds

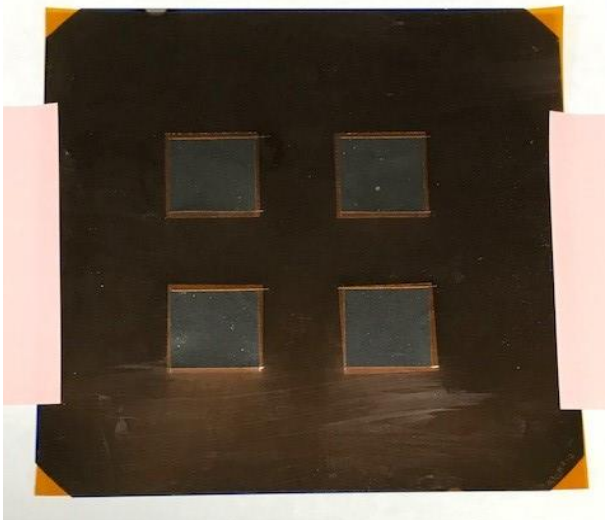
Sputter deposition

- Graphene backing for target material deposition
  - - Fabricated 4” enriched Boron-11 carbide sputtering target
  - Prepared graphene substrates
  - Deposited 200nm $^{11}B_4C$ on 0.1mg/cm^2 graphene: electrostatically attracted to substrate holder
  - Deposited 200nm $^{11}B_4C$ on 0.5mg/cm^2 graphene: substrate survived the film deposition in plasma

Sputter deposition (Cont.)

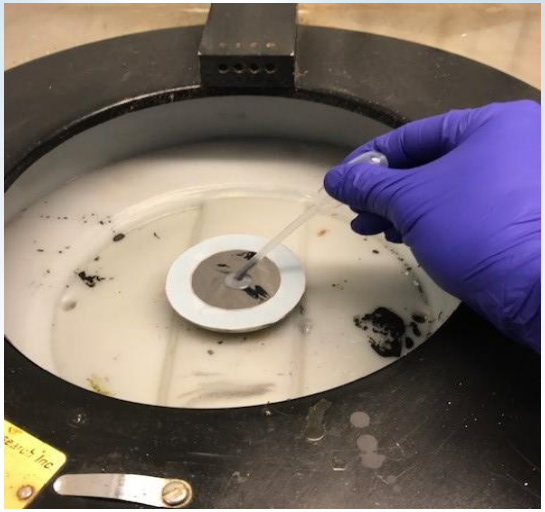
- Made two $^{11}B_4C$ sputter targets
  - 1/4” thick target cracked under heat load during sputtering
  - 1/8” thick target made but untested.
- Created better mounts for thin foil substrates to sputter B_4C coatings.

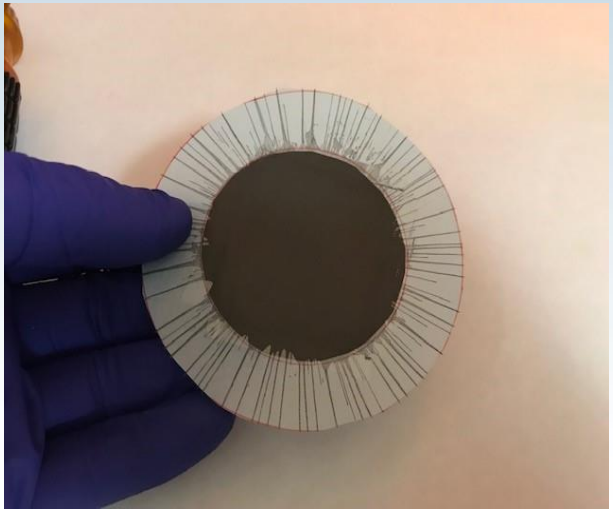




Four 20mm x 20mm graphene foil substrates mounted for B4C sputter deposition. Left – foils on wafer. Right – foils under Kapton mask.

Spin-coating on graphene substrates

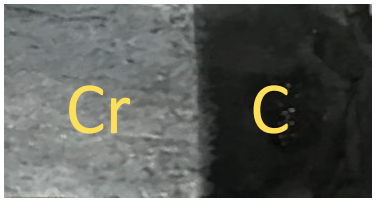




- Spin-coating works
- Made W and Re targets
- Not efficient use of expensive materials

Plating of targets

- Developed plating solutions for ^{52}Cr
- Electroplating on graphene is difficult
  - Works best if there is a very thin sputter layer of natural Cr.
  - Plating much easier on CNT+graphene foils. Foils are stiffer and high nucleation site number.
  - Plating targets is difficult and labor extensive – not an easy or efficient approach.



Target material in carbon matrix

- Graphene and CNT-enhanced graphene (preferred) foils made from dispersion after filtering through a membrane.
- Can add other materials to the dispersion that will be trapped in the carbon matrix when filtered.
- Process is easy and compatible with many materials (not compatible with material that dissolves or reacts with water).
- Process is highly efficient – all material in dispersion is in target.
- Examples include:
  - 5 mg/cm^2 Re + 2 mg/cm^2 carbon
  - 9.4 mg/cm^2 ^{10}B + 5 mg/cm^2 carbon
  - Others, $^{nat}HfO_2$, $^{nat}WO_3$, ^{nat}Ir
- Preferred method of making a target!

125mm diameter,
250mm diameter possible

Commercialization

- Sold $5,900 in 2019
- Sold $5,900 in 1st half of 2020 (end of Ph2)
- Exploring other opportunities to leverage this technology for medical-relevant isotopes.

- Questions?
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- **Thank you!!!**