Applied Nanotech, Inc.

inc. Design Center

Graphene Backing for Radioisotope Targets

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Applied Nanotech, Inc.

Outline

- Who is Applied Nanotech (ANI)?
- Prior effort using graphene
- Problem – need for radioisotope targets
- Approach – using graphene material
- Phase II and future effort

About ANI

- Located in Austin, Texas
- Founded 1988, publicly traded
- In 2014, merged with Nanofilm (Cleveland, OH), both are now subsidiaries of PEN Inc.
- Nanotechnology R&D emphasis:
  1) Graphene foils and films
  2) Printed Electronics
  3) Sensors
  4) Thermal Management
- PEN has staff of 20+ employees, ANI has 6 staff

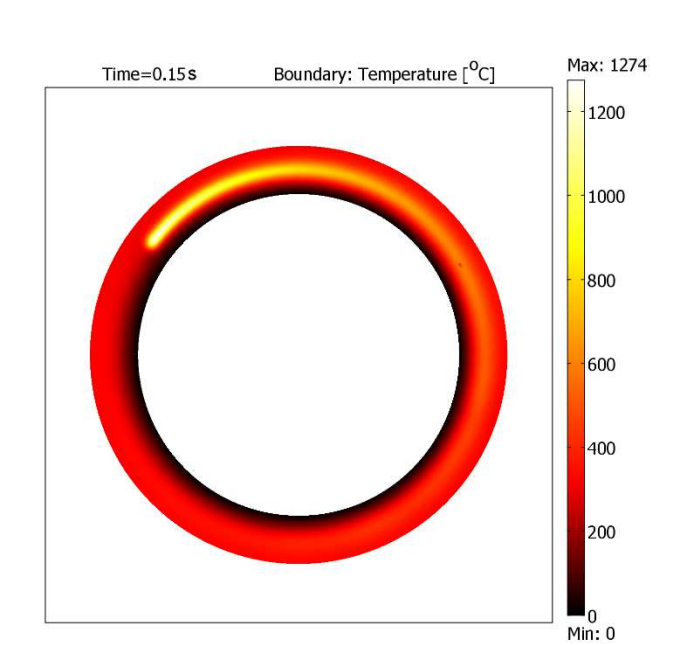
Prior ANI Effort Using Graphene

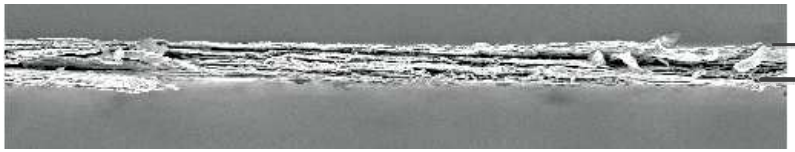
- Graphene based cold cathodes for flat panel displays
  - US Pat. 6,819,034 (2000, Pavlovsky) “Carbon flakes … can be as thin as one or more layers of sp2-bonded carbon atoms (graphite layers)”
- Isotopic Carbon Graphene Foil Targets
  - DoE grant DE-SC0015140: The goal of this program is to develop ^{13}C and ^{14}C carbon targets for nuclear experiments
  - Fabricated ^{nat}C graphene targets, while commercially available ^{13}C did not graphitize
  - Low risk approach for ^{14}C that has high levels of impurities is to print 3-5 mg/cm^2 films using a binder (2% wt.)
  - Test run complete at ANL in June 2018

Prior ANI Effort Using Graphene

- Graphene Stripper Foils for FRIB
  - DoE grant DE-SC0000852: The goal of this program was to develop a high thermal conductivity, rigid, large area, uniform graphene foil for charge stripping in accelerators, capable of having long lifetime
  - Fabricated by filtration of reduced GO. Size up to 5”, 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 carbon foils

Prior ANI Effort Using Graphene





- The foils are smooth and have a metallic luster
- The foils have a layered structure
- Foils are robust, easy to handle and survive express shipping

Problem

A variety of 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.

- Effective methods of target fabrication are needed

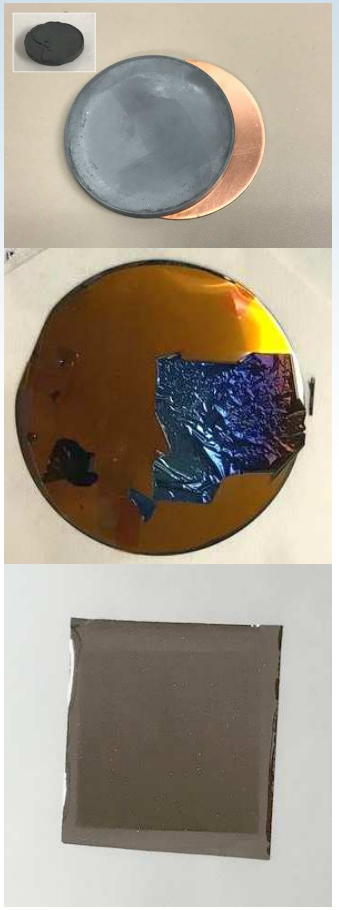
- **This program: Graphene Backing for Radioisotope Targets**
- **DoE Grant DE-SC0017208, currently Phase II (Topic 26(e) - Specialized Targets for Nuclear Physics Research)**

Approach

- **Use thin graphene backing films for target fabrication by magnetron sputtering: deposit enriched B-11 carbide**
- **Use graphene as a cathode for electroplating of isotopes: prepared Cr(III) bath to fabricate ^{nat}Cr plated target**
- **Use graphene as a matrix for composite targets where the target material is in the nanoparticle form. ^{nat}Ir nanoparticles were synthesized and used to fabricate ^{nat}Ir target with up to 50% target material mass loading.**

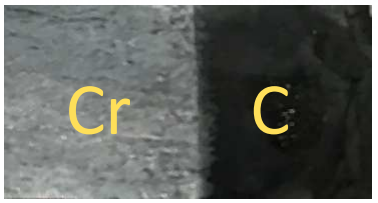
Phase I Results

- 1. Graphene backing for target material deposition
  - - Fabricated 3” 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



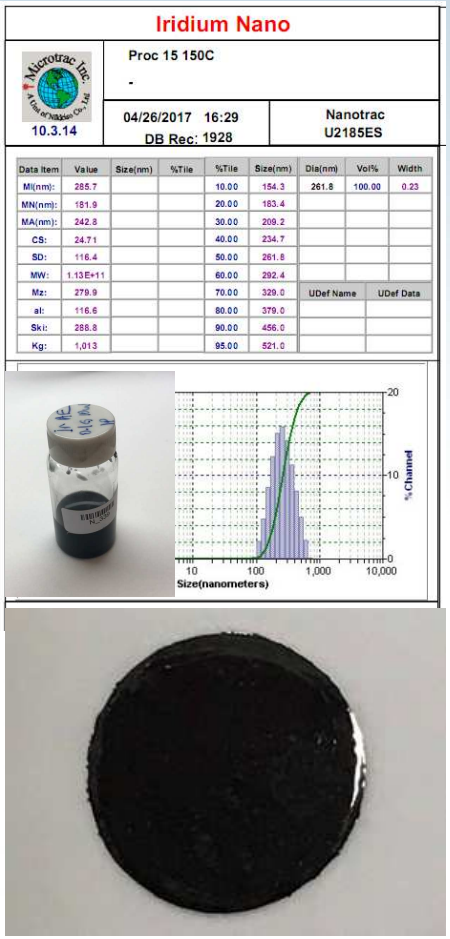
Phase I Results

- 2. Graphene backing for electroplating
  - Prepared 0.5mg/cm^2 graphene substrates (cathodes)
  - Formulated Cr(III) chloride electroplating bath and tuned a plating system
  - Plated 1mg/cm^2 natural Chromium targets on graphene substrates



Phase I Results

- 3. Graphene matrix with nanoparticle target materials
  - Prepared ^{nat}Ir nanoparticles by reduction of H_2IrCl_6 in aqueous solution
  - Pressure filtration of graphene and target material aqueous dispersions
  - Prepared 2mg/cm^2 free-standing natural Ir targets in graphene matrix at 50%wt. loading



Phase II Goals

- **Objective 1:** Demonstrate refractory metal targets (Nb, Re*) in graphene matrix with metal mass loading of 50% or greater
- **Objective 2:** Demonstrate sputtering deposition of $^{11}B_4C$ films on graphene backing with mass area density not exceeding 0.1 mg/cm^2
- **Objective 3:** Demonstrate W and Re* targets with area density ranging from 0.5 to 5 mg/cm^2 fabricated by spin coating over graphene backing
- **Objective 4:** Demonstrate electroplated ^{52}Cr isotopic targets with area density up to 1 mg/cm^2.
- **Objective 5:** Demonstrate ^{nat}Cu targets with area density up to 1 mg/cm^2 electroplated over graphene foils

*Excluded the initially proposed Mo target development per DoE request

Phase II Schedule

Task or Milestone	M1	M2	M4	M6	M8	M10	M12	M14	M16	M18	M20	M22	M24
MS1 - Program kickoff meeting	X												
Task 1: Obtain target materials, chemicals, prepare graphene films													
Subtask 1a. Obtain materials, chemicals, components													
Subtask 1b. Fabricate graphene films for the following tasks													
MS2 - All materials needed for the program are available				X									
Task 2: Fabricate W targets by spin coating over graphene													
Subtask 2a. Fabricate spin-coated W target on graphene													
Subtask 2b. Fabricate spin-coated Mo target on graphene													
MS3 - Spin coated targets are fabricated					X								
Task 3: Electroplating Cu and Cr-52 targets													
Subtask 3a. Electroplate Cu target on graphene film													
Subtask 3b. Optimize natCr electroplating conditions													
Subtask 3c. Electroplate Cr-52 target on graphene film													
MS4 - Cr-52 target electroplating complete							X						
MS5 - Year I Technical Report Complete							X						
Task 4: Sputtering of B-11 carbide on 0.1 mg/cm2 graphene													
MS6 - B-11 carbide deposited on thin graphene film									X				
Task 5: Refractory metal targets fabrication													
Subtask 5a. Fabricate W target in graphene matrix													
Subtask 5b. Fabricate Nb target in graphene matrix													
Subtask 5c. Fabricate Mo target in graphene matrix													
MS7 - Refractory metals targets fabricated													X
Task 6: Target fabrication per ANL request													
MS8 - Order fulfilled													X
Task 7: Program Management													
MS9 - Final Report complete													X

Phase II Deliverables

- Deliverables include:
  - Progress Reports (RPPRs) and Final Report
  - Deliverables to be evaluated at ANL:
    - $^{11}B_4C$ films on graphene backing
    - spin coated W and Re targets
    - Nb, Re nanoparticle targets in graphene matrix
    - Electroplated ^{52}Cr isotopic targets and ^{nat}Cu targets
- Delivered to date:
  - Ir, Re, WO_3, HfO_2 natural isotopic targets in graphene matrix with ~50% mass loading
  - Re nanoparticles fabricated in house, other materials obtained commercially

Future Plans

- **Test Ir and Re targets in graphene matrix at ATLAS**
- **Fabricate specialty isotopic targets for NP community**
- **Develop methods and targets for production of radiopharmaceuticals**
- **Possible application: graphene windows for X-ray sources and low energy particle beams**

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