Development of High Resolution Focusing Optics for Small Animal Radionuclide Imaging

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Outline

- Radionuclide Imaging
- Existing Technologies – Limitation
- Approach – Wolter Configuration Optics
- Specifications
- Fabrication
- Present Status
- Conclusion

UAH

Small Animal Radionuclide Imaging

- Radionuclide imaging is an imaging technique used in nuclear medicine
- Small animal research – extrapolated to human diagnosis
- A radioactive isotope is attached to a biologically active molecule and injected into the living subject
- Organ malfunctioning - isotope is either taken up partially or in excess by the organ
- Powerful diagnostic tool because
  - Non invasive nature of the technique
  - Ability to observe from outside the body

Existing Techniques

- MRI (Magnetic Resonance Imaging)
- CT (Computed Tomography)

} high resolution of 25-50 µm limited to anatomical studies

- PET (Positron Emission Tomography)
- SPECT (Single Photon Emission Computed Tomography)

} ~ 1 mm resolution

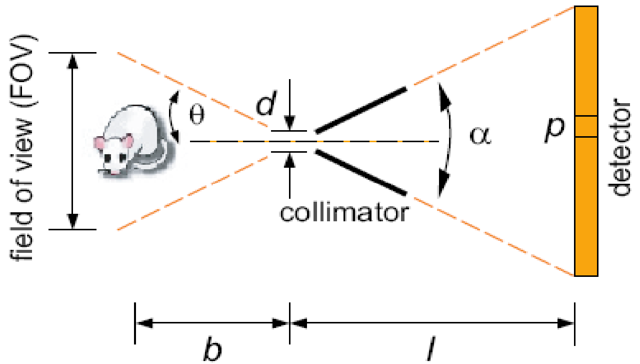
- Why improved resolution?

  example – Carcinogenesis, normal cell transforming into cancer cell – should be identified as soon as possible so that it can be monitored and cured efficiently

Limitation of Existing Technique

SPECT

- Pinhole serves as the optical element



(Ref – Progress of focusing X-ray and Gamma-ray optics for small animal imaging – M.J.Pivovaroff, T. Funk, W.C. Barber, B.D. Ramsey, B.H. Hasewaga – Aug8 2005 – Penetrating Radiation and Applications VII, SanDiego)

- Decrease in the aperture size – improves system resolution linearly – degrades efficiency quadratically
- Requires critical tradeoff between spatial resolution and detection efficiency
- Investigate using reflective optics – targeted resolution of 100 µm or better
- This reflective optics has been successfully implemented in x-ray telescopes

Specifications

Working energy

- The optical system would be optimized to focus either the ***18 keV*** photons emitted by ^{99m}Tc or the ***27 keV*** photons emitted by ^{125}I

Resolution

- Biological sciences field has the requirement of ***100 µm*** or better spatial resolution

Field of view

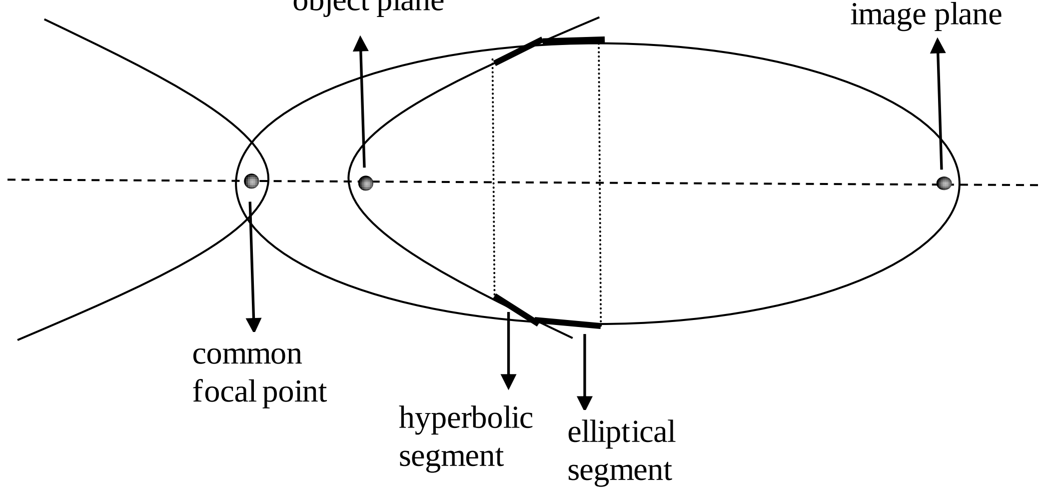
- Field of view selected should be capable enough to visualize the biomolecular processes in small animals - Targeted field of view is ***1 - 2 cm***

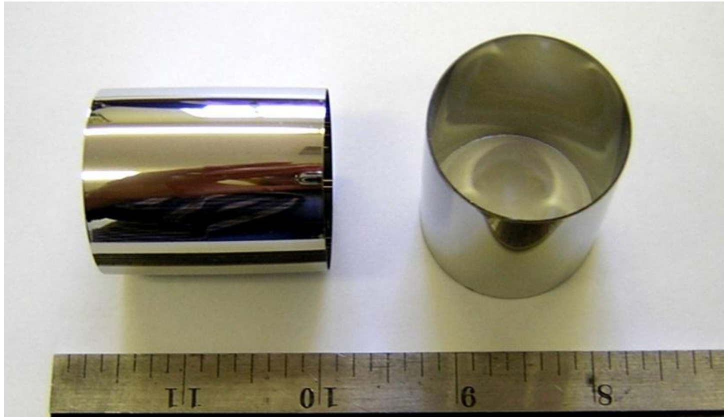
Efficiency

- Targeted efficiency is
  $7*10^{-5}$ for ^{125}I optics with 20 to 40 shells
  $4*10^{-4}$ for ^{99m}Tc optics with 40 to 70 shells

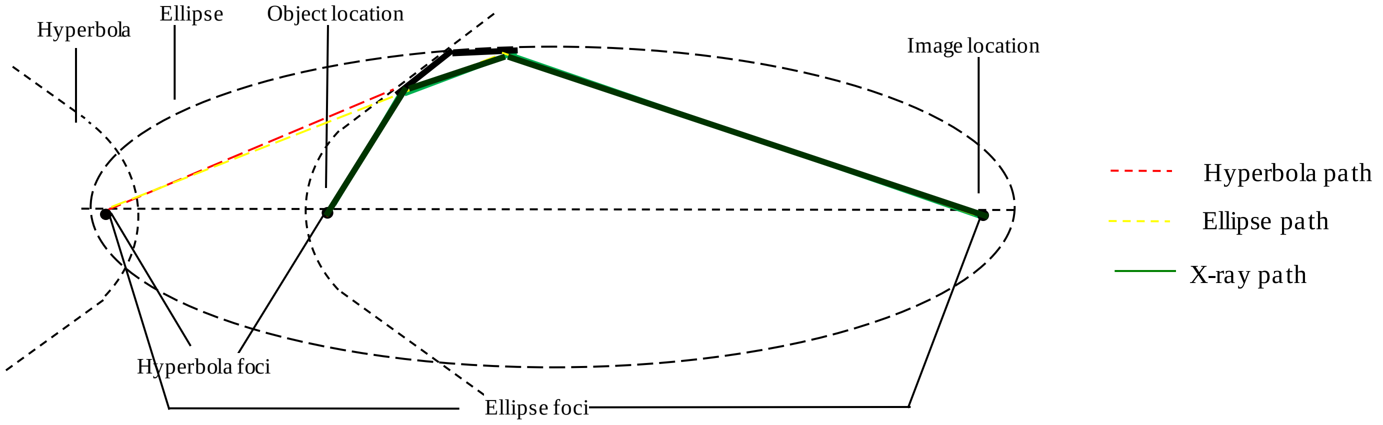
Wolter Configuration Optics

- Wolter configuration optics utilizes total external reflection of x-rays
- Wolter configuration optics is a pair of mirrors built from the surfaces of revolution of conic sections (in this case hyperbola and ellipse)



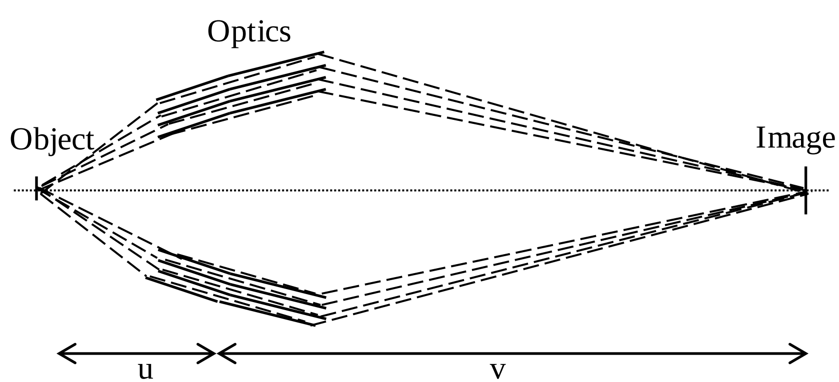


Grazing Incidence Optics



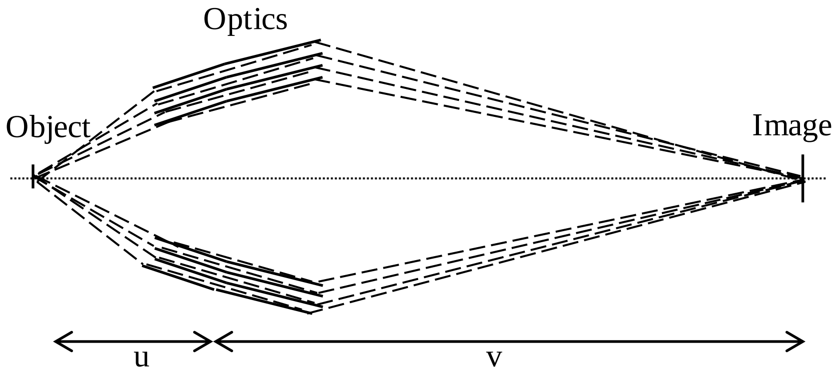
Wolter Optical Design

Total length = 3 m
Object distance (u) = 0.6 m
Image distance (v) = 2.4 m
Magnification = 4
Reflection angle = 0.5 deg



Group of 4 shells nested together

- 20 - 40 nested shells for ^{125}I (27 keV)
- 40 - 70 nested shells for ^{99m}Tc (18 keV)
- 4 shells as a prototype – efficiency 10-20% of complete optics, field of view and spatial resolution same as final optics



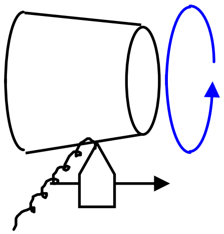
Group of 4 shells nested together

- Optics is made of Co/Ni alloy
- Optics is Multilayer coated – to enhance the reflectivity – tuned for ^{125}I, ^{99m}Tc

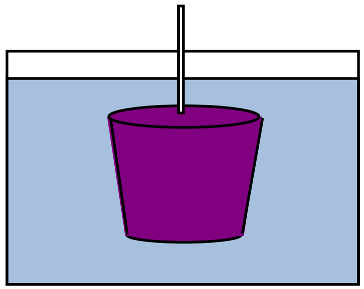
Electroformed Nickel Replication Process

Mandrel Preparation

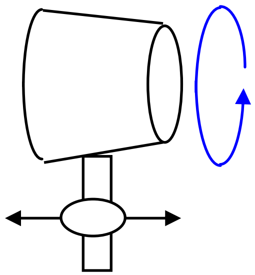
1. CNC machine, mandrel formation from Al bar



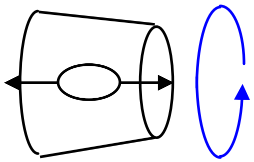
2. Chemical clean and activation & electroless Nickel (EN) plate



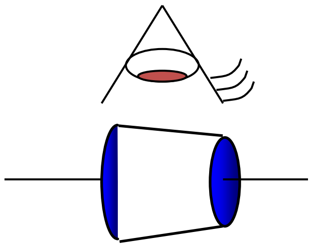
3. Precision diamond turning to 20 Å, sub-micron figure accuracy



4. Polish and superpolish to 3 – 4 Å rms finish

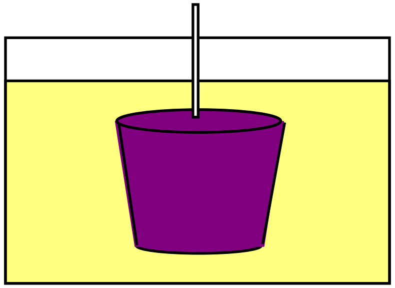


5. Metrology on mandrel

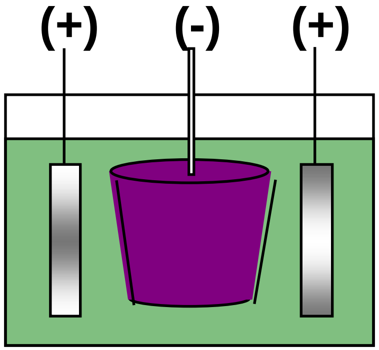


Shell Fabrication

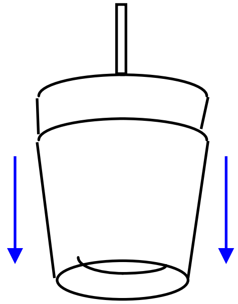
6. Ultrasonic clean and passivation to remove surface contaminants



7. Electroform Ni/Co shell onto mandrel



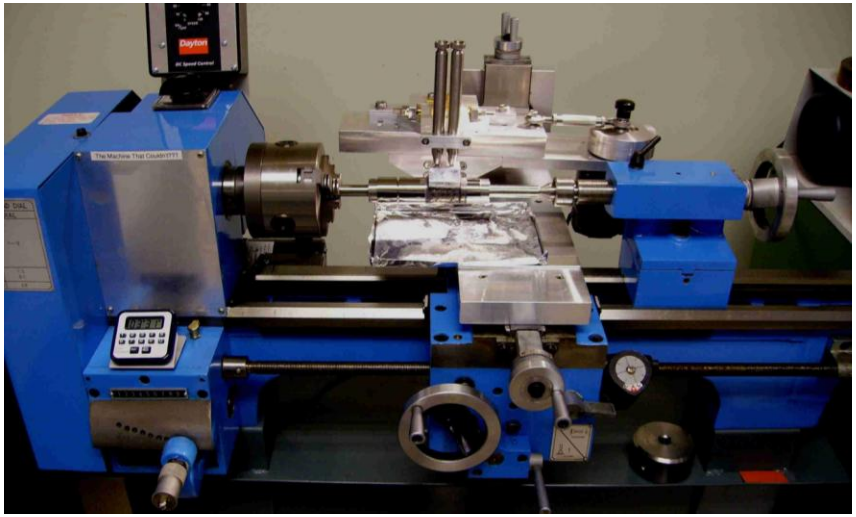
8. Separate optic from mandrel in cold water bath



Photograph of a optics and mandrel

Present Status

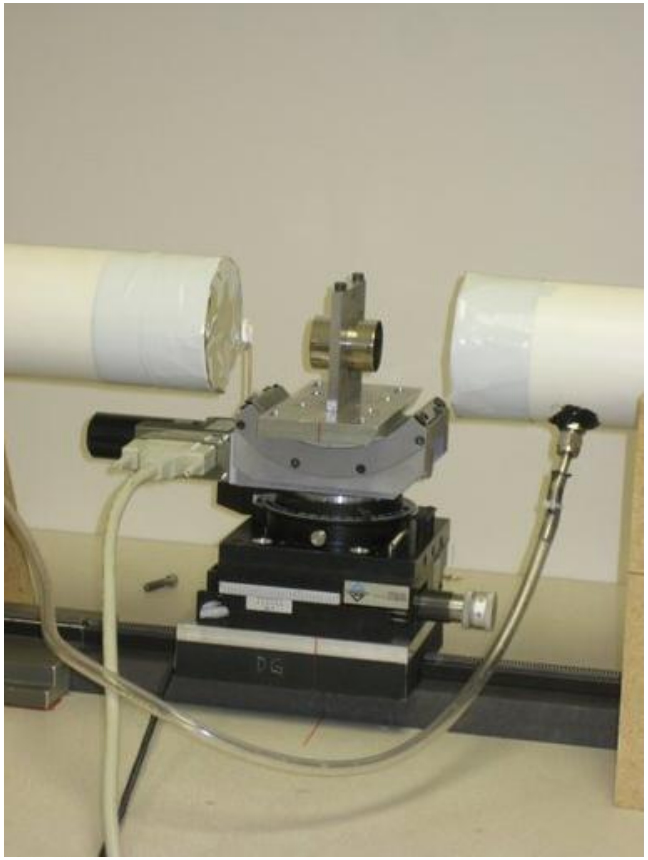
- Fabrication of one mandrel is complete



- Fabrication of the second mandrel by end of August
- Testing of the multilayer coated prototype optics by the end of December
- Experimental set up to test the prototype optics

Experimental set up used to characterize the performance of optics

Optics mounted on the rotational stage



Detector — Optics — Source

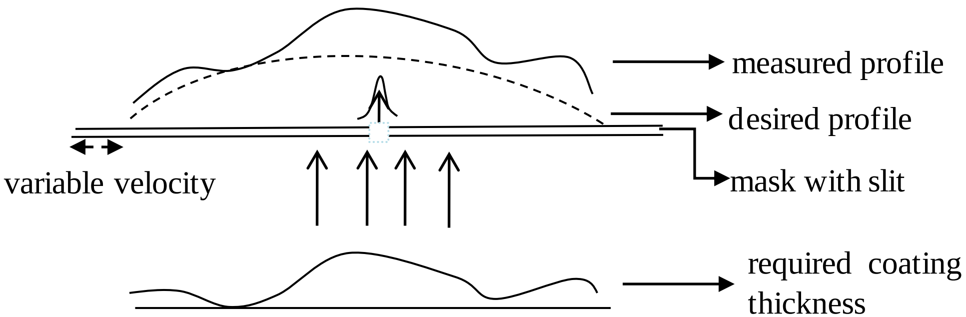
2400mm 600mm

Detector Optics Source

• 100 µm resolution attainable with regular process can be further improved

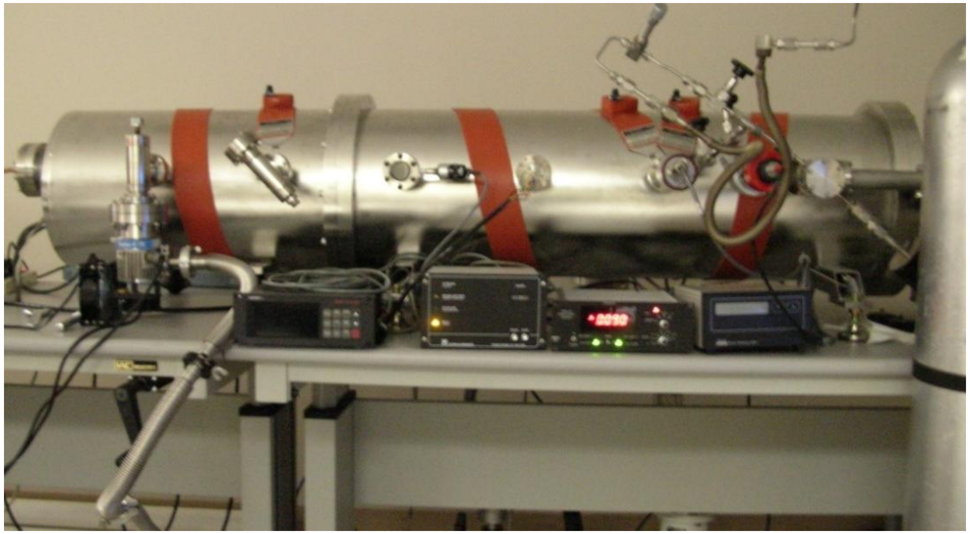
Differential Coating

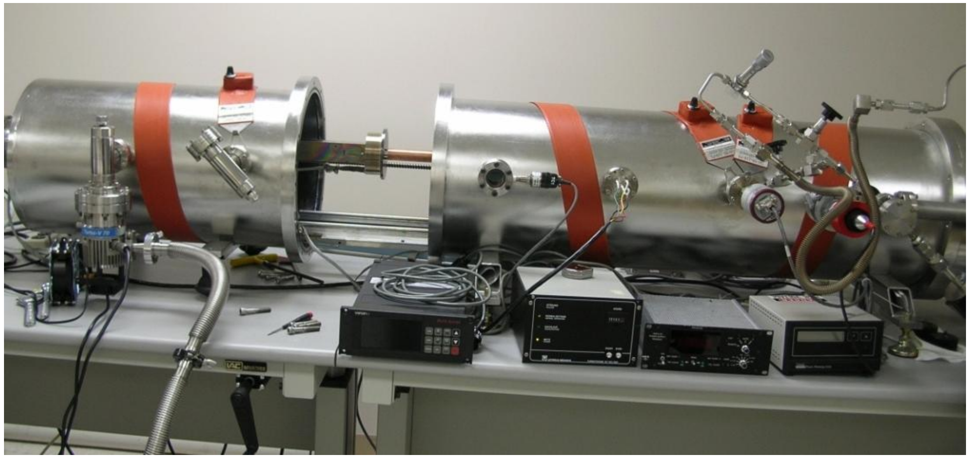
- Irregularities in surface profile are corrected using the differential coating technique
- Radio Frequency sputtering technique is used
- A mask with a slit is scanned along length of the optics with variable velocity
- Higher coating thickness required – slower velocity of the mask



Differential coating is used to minimize the variations in the surface profile.

Vacuum Coating Chamber





Conclusion

- This is a novel approach for an improved resolution (100 µm or better) in small animal radionuclide imaging
- We are developing two prototype optics with 4 shells each - as a proof of concept
- We are investigating a differential coating technique to correct irregularities in the surface profile
- Long term goal of the project is to develop an *in vivo* gamma-ray microscopy system that has 100 µm spatial resolution, high sensitivity and a wide field of view capable of visualizing biomolecular processes in small animals