NASA SBIR 2018 Phase I Solicitation

S2.04 X-Ray Mirror Systems Technology, Coating Technology for X-Ray-UV-OIR, and Free-Form Optics

Lead Center: GSFC

Participating Center(s): JPL, MSFC

Technology Area: TA8 Science Instruments, Observatories & Sensor Systems

This subtopic focuses on three areas of technology development:

- X-Ray manufacturing, coating, testing, and assembling complete mirror systems in addition to maturing the current technology.
- Coating technology including Carbon Nanotubes (CNT) for wide range of wavelengths from X-Ray to IR: X-Ray, EUV (extreme ultraviolet), LUV (Lyman ultraviolet), VUV (vacuum ultraviolet), Visible, and IR (infrared) telescopes.
- Free-form Optics design, fabrication, and metrology for CubeSat, SmallSat and various coronagraphic instruments.

A typical Phase I proposal for X-Ray technology would address the relevant optical sub-component of a system with necessary coating and stray light suppression for X-Ray missions or prototype demonstration of a fabricated system and its testing. Similarly, a Coating technology proposal would address fabrication and testing of optical surfaces for a wide range of wavelengths from X-Ray, EUV, LUV, VUV, Visible and IR. The Free-form Optics proposals tackle the challenges involved in design, fabrication, and metrology of non-spherical surfaces for small-size missions such as CubeSat, NanoSat, and coronagraphic instruments.

In a nutshell, a successful proposal demonstrates a low-cost ability to address NASA science mission needs and technical challenges specified under each category with feasible plan to develop the technology for infusion into NASA Decadal class missions and sub-orbital rockets and/or balloon for IR-class telescopes.

The National Academy Astro2010 Decadal Report identifies studies of optical components and ability to manufacture, coat, and perform metrology needed to enable future X-Ray observatory missions such as Next Generation of X-Ray Observatories (NGXO).Â The Astrophysics Decadal specifically calls for optical coating technology investment for future UV, Optical, Exoplanet, and IR missions while Heliophysics 2009 Roadmap identifies the coating technology for space missions to enhance rejection of undesirable spectral lines, improve space/solar-flux durability of EUV optical coatings, and coating deposition to increase the maximum spatial resolution.

Future optical systems for NASAs low-cost missions, CubeSat and other small-scale payloads, are moving away from traditional spherical optics to non-spherical surfaces with anticipated benefits of freeform optics such as fast wide-field and distortion-free cameras.

X-Ray Optical Component, Systems, and Technologies

NASA large X-Ray observatory requires low-cost, ultra-stable, light-weight mirrors with high-reflectance optical coatings and effective stray light suppression. The current state-of-art of mirror fabrication technology for X-Ray missions is very expensive and time consuming. Additionally, a number of improvements such as 10 arc-second angular resolutions and 1 to 5 m^2 collecting area are needed for this technology. Likewise, the stray-light suppression system is bulky and ineffective for wide-field of view telescopes.

In this area, we are looking to address the multiple technologies including: improvements to manufacturing (machining, rapid optical fabrication, slumping or replication technologies), improved metrology, performance prediction and testing techniques, active control of mirror shapes, new structures for holding and actively aligning of mirrors in a telescope assembly to enable X-Ray observatories while lowering the cost per square meter of collecting aperture and effective design of stray-light suppression in preparation for the Decadal Survey of 2020. Currently, X-Ray space mirrors cost $4 million to $6 million per square meter of optical surface area. This research effort seeks a cost reduction for precision optical components by 5 to 50 times, to less than $1M to $100 K/$m^2$.

Coating Technologies for X-Ray, EUV, LUV, UV, Visible, and IR Telescopes

The optical coating technology is a mission-enabling feature that enhances the optical performance and science return of a mission. Lowering the areal cost of coating determines if a proposed mission could be funded in the current cost environment. The most common forms of coating used on precision optics are anti-reflective (AR) coating and high reflective coating. The current coating technology of optical components needs to achieve TRL-6 by approximately 2018 to support the 2020 Astrophysics Decadal process. A number of optical coating metrics specific to each wavelength are desired such as:

The Optical Coating Metrics

The telescope optical coating needs to meet low temperature operation requirement. Its desirable to achieve 35 K in future.

X-Ray Metrics:Â

- Multilayer high-reflectance coatings for hard X-Ray mirrors similar to NuSTAR.
- Multilayer depth gradient coatings for 5 to 80 KeV with high broadband reflectivity.
- Zero-net-stress coating for iridium or other high-reflectance elements on thin substrates (< 0.5 mm).

EUV Metrics:Â

- Reflectivity > 90% from 6 nm to 90 nm and the ability to be applied onto a < 2-meter mirror substrate.

LUVOIR Metrics:Â

- Broadband reflectivity > 70% from 90 nm to 120 nm (LUV); > 90% from 120 nm to 2500 nm (VUV/Visible/IR); Reflectivity non-uniformity < 1% from 90 nm to 2500 nm. Induced polarization aberration < 1% from 400 nm to 2500 nm and depositable onto 1 to 8 m substrates.

Non-Stationary Metric:Â

- Non- uniform optical coating to be used in both reflection and transmission that vary with location and optical surface. Variation pertains to ratio of reflectivity to transmissivity, optical field amplitude, phase, and polarization change. The optical surface area ranges from 1/2 to 6 cm.

Scattered Light Suppression Using Carbon Nanotube (CNT) Coating

A number of future NASA missions require suppression of scattered light. For instance, the precision optical cube utilized in a beam-splitter application forms a knife-edge that is positioned within the optical system to split a single beam into two halves. The scattered light from the knife-edge could be suppressed by CNT coating.Â Similarly, the scattered light for gravitational-wave application and lasercom system where the simultaneous transmit/receive operation is required, could be achieved by highly absorbing coating such as CNT. Ideally, the application of CNT coating needs to achieve:

- Broadband (visible plus Near IR), reflectivity of 0.1% or less.
- Resist bleaching of significant albedo changes over a mission life of at least 10 years.
- Withstand launch conditions such vibe, acoustics, etc.
- Tolerate both high continuous wave (CW) and pulsed power and power densities without damage. ~10 W for CE and ~ 0.1 GW/cm^2 density, and 1 kW/nanosecond pulses.
- Adhere to the multi-layer dielectric or protected metal coating including Ion Beam Sputtering (IBS) coating.

Freeform Optics Design, Fabrication, and MetrologyÂ

Future NASA missions with alternative low-cost science and small-size payload are constrained by the traditional spherical form of optics. These missions could benefit greatly by the freeform optics as they provide non-spherical optics with better aerodynamic characteristics for spacecraft with lightweight components to meet the mission requirements. Currently, the design and utilization of conformal and freeform shapes are costly due to fabrication and metrology of these parts. Even though various techniques are being investigated to create complex optical surfaces, small-size missions highly desire efficient small packages with lower cost that increase the field of view and expand operational temperature range of unobscured systems. For the coronagraphic applications, freeform optical components allow coronagraphic nulling without shearing and increase the useful science field of view. In this category, freeform optical prescription for surfaces of 0.5 cm to 6 cm diameters with tolerances of 1 to 2 nm rms are needed. In this respect, the freeform refers to either 2nd order conic prescription with higher order surface polished onto it or without underlying conic prescription with no steps in the surface. The optics with underlying conic prescription would need to be in F/# range of F/2 to F/20. In addition to the freeform fabrication, the metrology of freeform optical components is difficult and challenging due to the large departure from planar or spherical shapes accommodated by conventional interferometric testing. New methods such as multibeam low-coherence optical probe and slope sensitive optical probe are highly desirable.

Ultra-Stable X-Ray Grazing-Incident Telescopes for Sub-Orbital Balloons and Rocket-Borne Missions

Technology maturation to build complete low-cost, lightweight X-ray telescopes with grazing-incident optics that can be flown on potential long duration high-altitude balloon-borne or rocket-borne missions. The focus here is to reduce the areal cost of telescope by 2x such that the larger collecting area can be produced for the same cost or half the cost.Â