A Vacuum Spark Point Source for EUV Lithography

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Agenda

- Introduction
- Vacuum Spark Technology
- System Advantages
- System Description
- Testing To Date
- Issues to Resolve
- Technical Roadmap
- Supportive Rationale
- Summary

Introduction

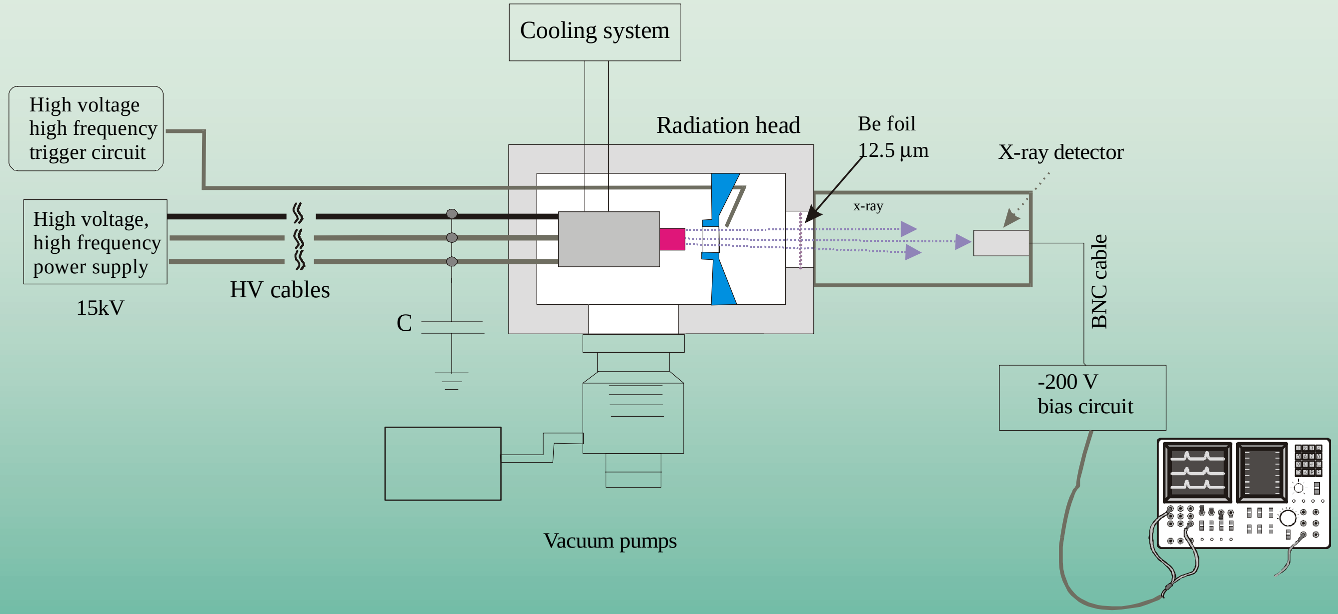
- Have devoted past 5 years to using VSX technology to create an X-ray Point Source.
- Through help from ASML, we recognize our discharge source could be a viable EUV Source.
- Believe strategy applied for XRL Point Source development can be applied to EUV Source.
- Initial results very promising.
- Need better measurement equipment and optics partner to develop our source for EUV application.

Why VSX Type Point Source ?

- Simple Concept
  - VSX consists of a condenser that charges and discharges in vacuum, the resultant metallic plasma generates radiation from hard X-ray to EUV wavelengths.
- Simple Concept to Increase Power
  - Each pulse produces a small amount of radiation.
  - Repeating the phenomenon at high frequency produces market-desired results.
- Simple Means to Achieved Desired Wavelength
  - Changing the anode material allows our Source to be ‘tuned’ to specific applications.

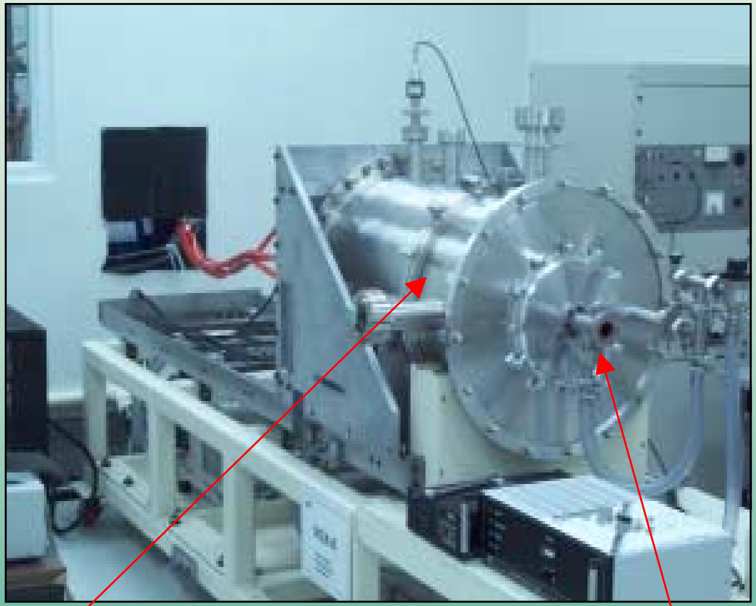
A Simple Solution to a Complex Problem

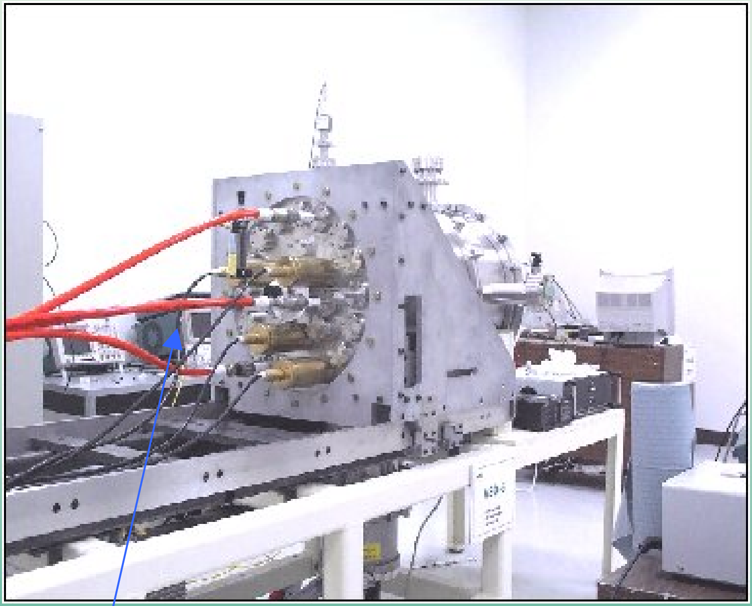
Schematic Diagram of VSX



- **Radiation Head, Power Supply, Cooling System, Vacuum Pump System, Signal Monitoring**

VSX-6 Prototype



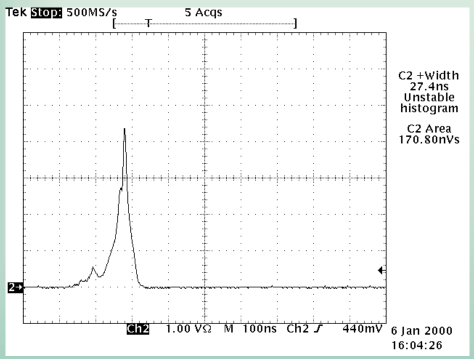


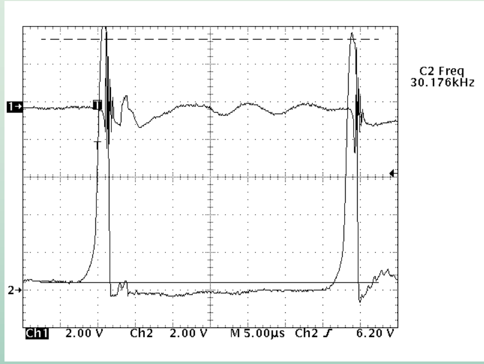
Vacuum Chamber

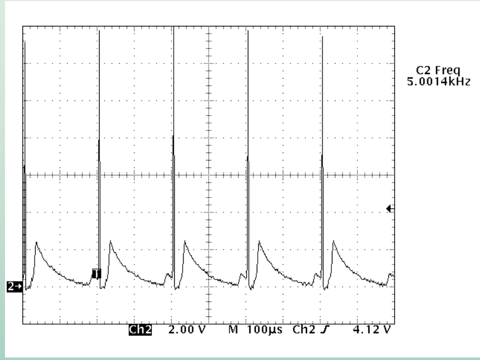
Radiation Emission Window

Anode Cooling Lines

VSX Typical Signal







- Pulse width (FWHM): < 30 ns
- Integrated Signal: 170 nVs
- XRD at 27 cm with 8µ *Be* filter
- Output energy per pulse: ~113 µJ
- Efficiency near 0.1%

5 kHz Signal

30 kHz Signal

Have Proven Operation to 100 kHz

Initial Testing Methods

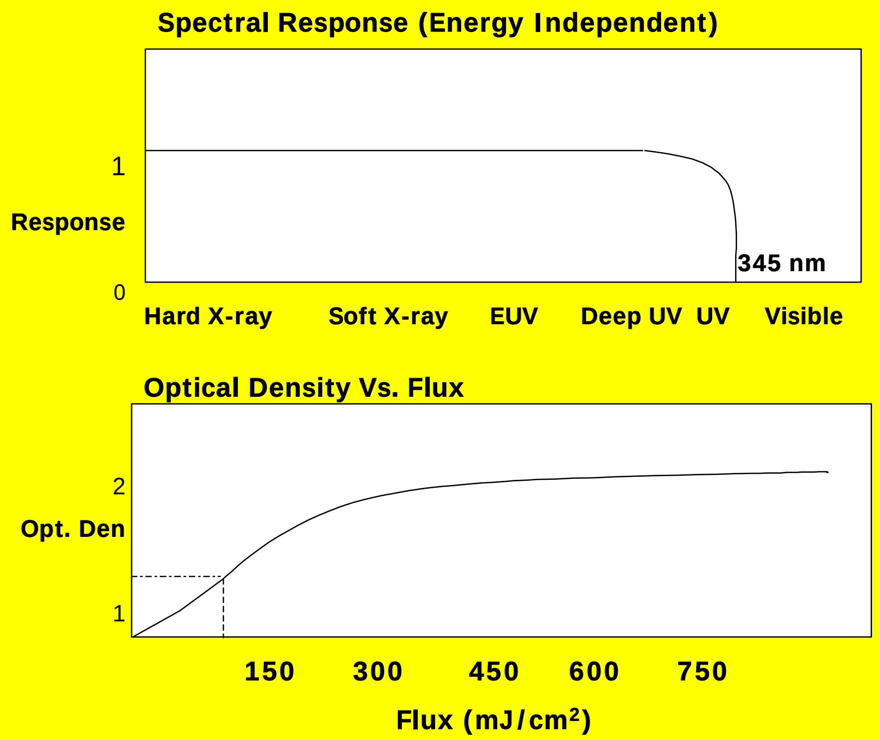
Filters

- Beryllium
- Quartz
- Glass
- No filter

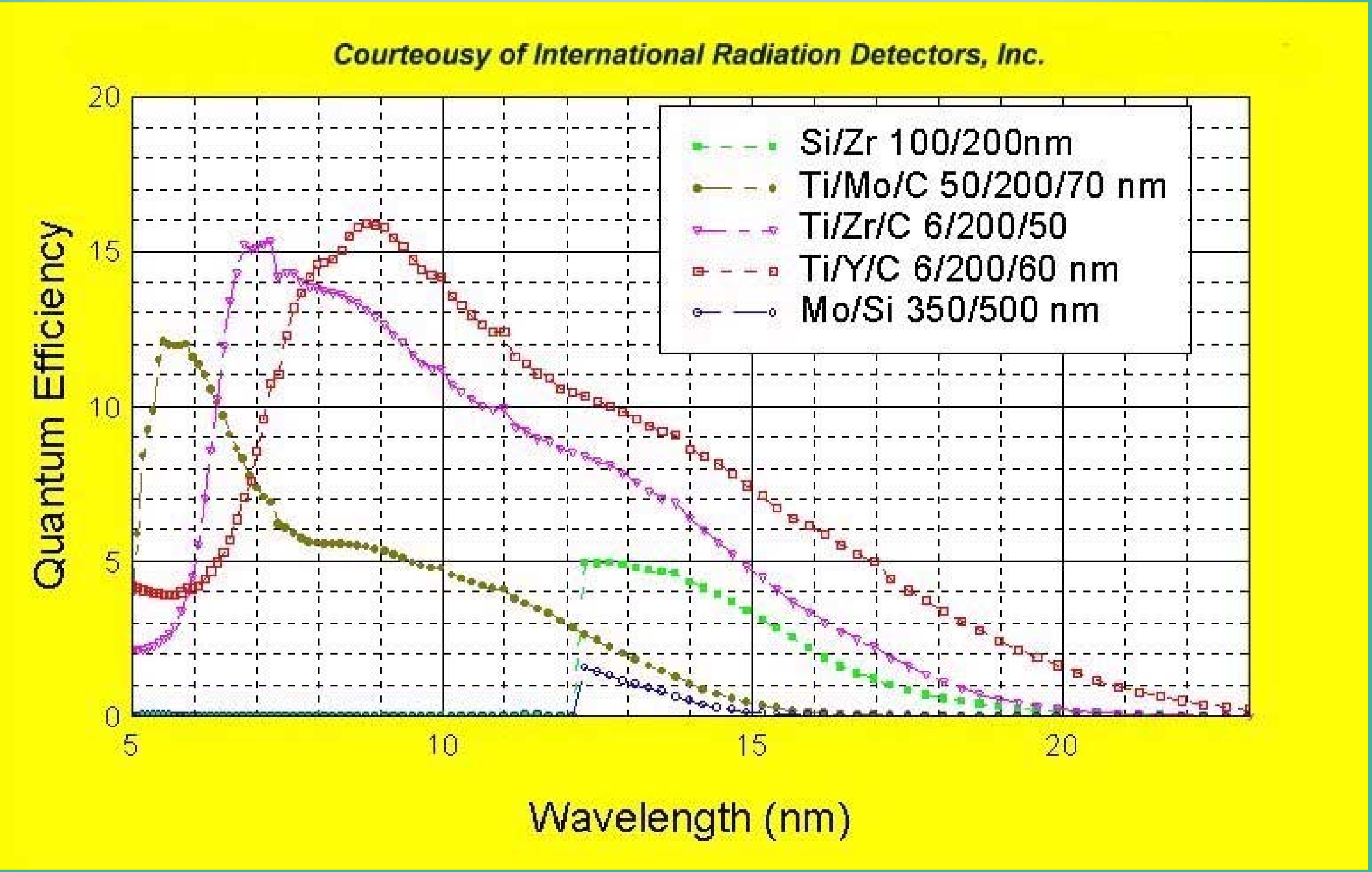
Detector

- Radiachromic film
- Pin Diode
  - X-ray
  - EUV

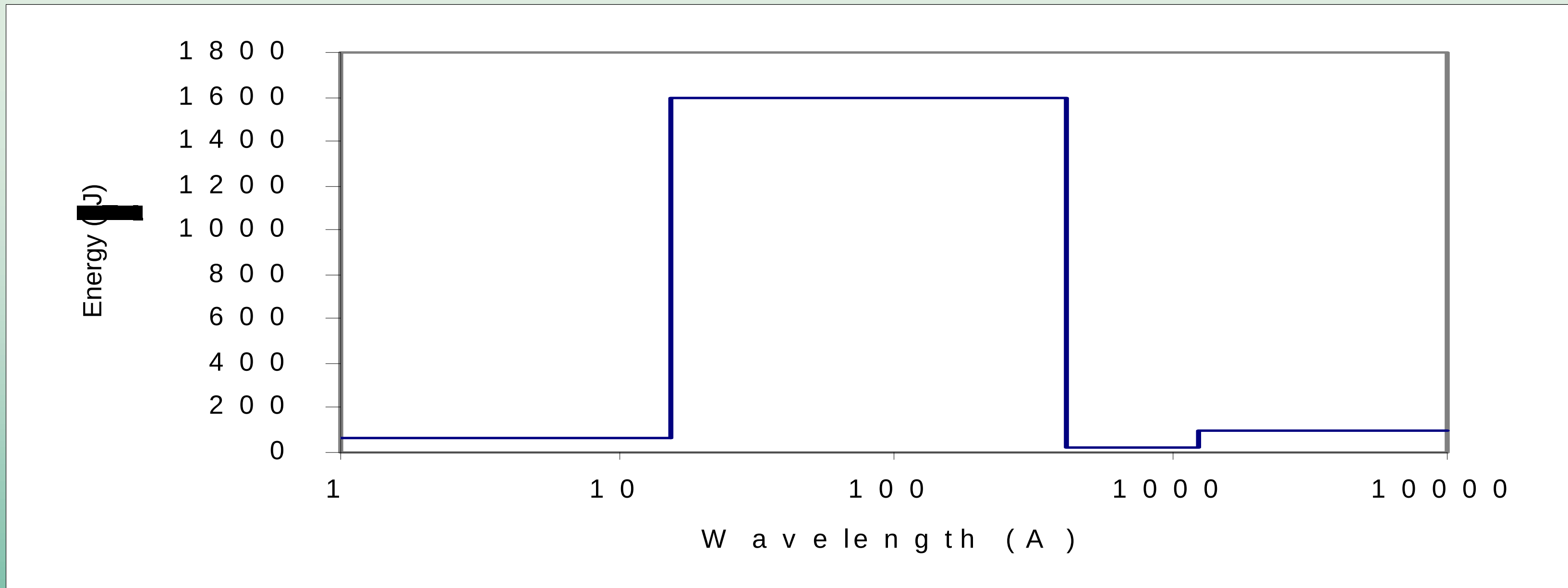
Radiachromic Film Characteristics



IRD AXUV Photodiodes with Integrated Filters for 13 nm



Test Results



Component	nVs	Energy(µJ)
X-ray (>800eV) or (<15.5 Å)	684	67
EUV(30eV-800eV) or (15.5-416.7 Å)	8767	1600
DUV (10eV-4eV) or (1240-3100 Å)	118	21
Visible (<4eV) or (>3100 Å)	560	102.2

Issues to Resolve

- Debris Management
  - Magnetic deflection
  - Electric deflection
- Thermal Management
  - Solvable through various cooling techniques (oil, water)
- Optics
  - Need partner - TBD

Technical Roadmap

	Now	In 1 year	In 2 years	Ultimo	Requirements for commercial tools[1]
Demonstrated collectable EUV power in a 2% spectral bandwidth in the region between 13 – 14nm	0.3 W[6]	5 W[7]	60 W[8]	100 W[9]	50 - 150 Watt
Available collection solid angle	4Π sphere, without collector	2 Π str collector	2 Π str collector	Π str collector	
Source emission volume dimensions	1.5 mm ∅ X 2 mm[10]	1.2. mm ∅ X 2mm	1 m ∅ X 1.5 mm	1 mm ∅ X 1 mm	

Technical Roadmap

	Now	In 1 year	In 2 years	Ultimo	Requirements for commercial tools[1]
Demonstrated maximum repetition rate	30 kHz	50 kHz	100 kHz	150 kHz	> 5000
Demonstrated steady-state repetition rate	16 kHz	30 kHz	60 kHz	100 kHz	
Dissipated total power (e.g. electrical or laser) in source region at steady-state repetition rate*	800 W	1.5 kW	3 kW	5 kW	

* Thermal modelling results to support projected steady-state repetition rate.

Technical Roadmap

	Now	In 1 year	In 2 years	Ultimo	Requirements for commercial tools
Source-facing condenser lifetime (pulses to 10% reflectance loss)	TBD[11]	1 week	1 month	1 year	1 year or 1.6 E+11 pulses
Pulse-to-pulse spatial stability[2]	1 mm	1 mm	< 1 mm	< 1 mm	
Pulse-to-pulse intensity stability[3]	± 15 %	± 10 %	± 7 %	± 0.5 %[12]	< 2 %
Pulse-to pulse angular stability[4]	TBD[13]			± 1.0 %[14]	

Technical Roadmap

	Now	In 1 year	In 2 years	Ultimo	Requirements for commercial tools
Pulse-to-pulse pointing stability[5]	5 %			2 %	
Key risk areas	Debris Mitigation, Heat Extraction, Ultimate Power Output, Electrodes Lifetime		Debris Mitigation, Electrodes Lifetime		
Critical component lifetime	8 hrs (1 hr MTTR)	24 hrs (30 min MTTR)	96 hrs (20 min MTTR)	168 hrs (20 min MTTR)	

Supportive Rationale to Roadmap

1. Requirements defined by int'l source workgroup in March 2000.
2. 3σ variation of EUV emission centroid position.
3. 3σ variation of in-band EUV flux.
4. 3σ variation of EUV radiant flux at widely separated angular positions.
5. 3σ angular variation of EUV the principal emission direction (if non-uniform).
6. At present, ALFT's source is primarily a soft X-ray source peaking at 1 nm. However, EUV radiation was effectively measured in the 2-20 nm bandwidth. The 0.3 W level was tentatively derived for a 4 Π sphere, without collector.
7. Assuming 2 Π str collector is available. The power increases as a result of higher repetition rate and moving the central wavelength to the EUV spectrum. This power is over a 25% bandwidth. The bandwidth is narrowed with optimization of the plasma source material for EUV application. The power increases as a result of higher repetition rate.

Supportive Rationale to Roadmap

8. The power increases as a result of moving the central wavelength to EUV spectrum. Further narrow the bandwidth with optimization of the plasma temperature for EUV application.
9. Power increased as a result of higher repetition rate. Assumes that a Π str collector with MoSi MLI coating that will further narrow the bandwidth to 7 % is available.
10. This source size was actually imaged at 1 nm.
11. No long-term experience with collectors at EUV wavelength to date.
12. With a higher repetition rate source, the granularity is better and the ± 4 % inherent stability becomes 0.5 % equivalent repeatability through external feedback.
13. The actual measurement of an X-ray source yields a spread of 60 % over a 90° solid angle.
14. Improvements achieved through electrode geometry.

Summary

- We will determine if our Source is suitable for EUV applications by year-end.
- Current output *may* be as high as 160 watts at 100kHz operation.
- Debris management will be our biggest concern as the rep rate is increased.
- Positive test results will provide rationale to build prototype in 2001 once funding is secured.