Dynamical Orbital Collapse Drives Super Xe(M) X-Ray Emission at λ ~ 12-14 Å for Lithographic Applications

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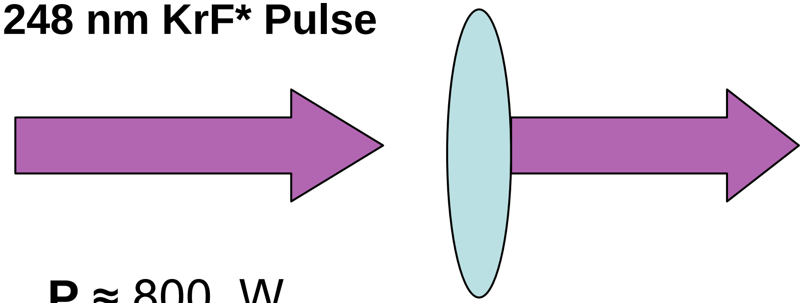
ABSTRACT

Experimental studies of the characteristics of Xe(M) emission (~12-14 Å) produced by multiphoton excitation of Xe clusters indicate that the nonlinear interaction automatically acts as a template leading to the preparation of the maximally radiating configurations for that spectral range. The new mechanism is a general multiphoton multi-electron process that dynamically combines rapid multiphoton ionization, 4f-orbital collapse, and correlated electron motion. In comparison with conventional modalities of excited state production, this is an entirely different mechanism of excitation that perforce optimizes the electronic configuration of the atom for rapid and efficient x-ray emission in the kilovolt range. These results point to the feasibility of producing efficient x-ray sources in the Lambda ~12-14 Å spectral region at average powers of several hundred watts for lithographic applications.

CONCEPT OVERVIEW

Driver

248 nm KrF* Pulse



P ≈ 800 W
R ≈ 4 kHz
E ≈ 200 mJ
τ < 1 ps

Modification of Existing Technology

Optical System

Available Technology

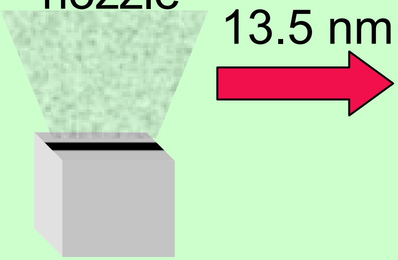
Power Compression System

Channels with Clusters

OR

Condensed Matter

Cluster Target



Clusters/Propagation/
Selective Excitations/
13.5 nm Amplification

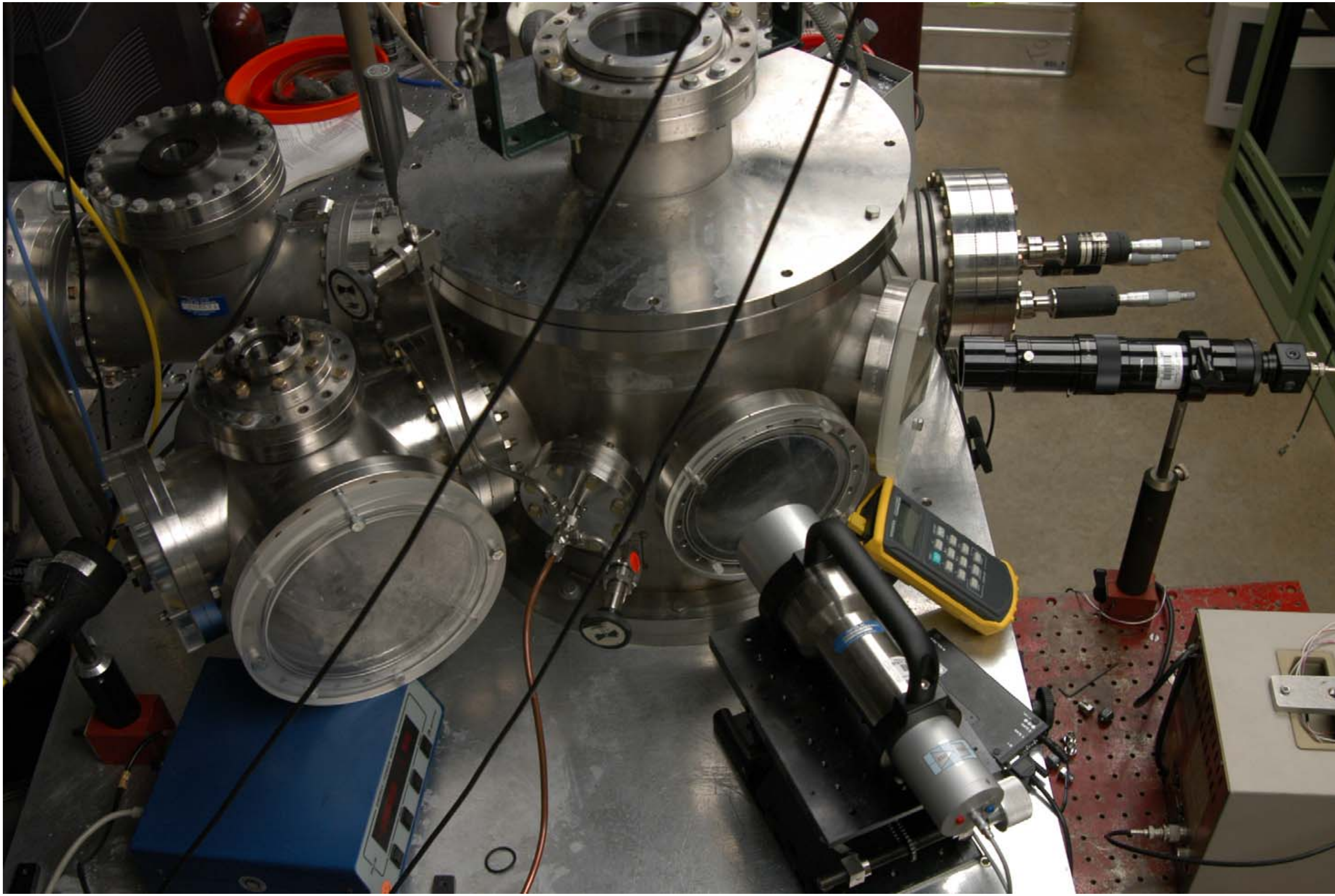
Proprietary Nozzle
Optimizes
Cluster Production, Density, and Propagation
Debris-Free Operation

KEY NEW PHYSICS

Cluster Formation Concept

- Enable Optimal Excitation at Solid Density
- Enable Plasma to be Thin, Permitting Propagation (Independent Control of Average Density)
- Give Proven Mechanism for Selective Inner-Shell Excitation (4d/3d/2p)
- Patented Concept
- Experimentally Proven Xe(L), $\lambda \sim 2.9$ Å [*J. Phys. B.* **36**, 3433 (2003)]
- Experimentally Proven Xe(M), $\lambda \cong 12.6$ Å

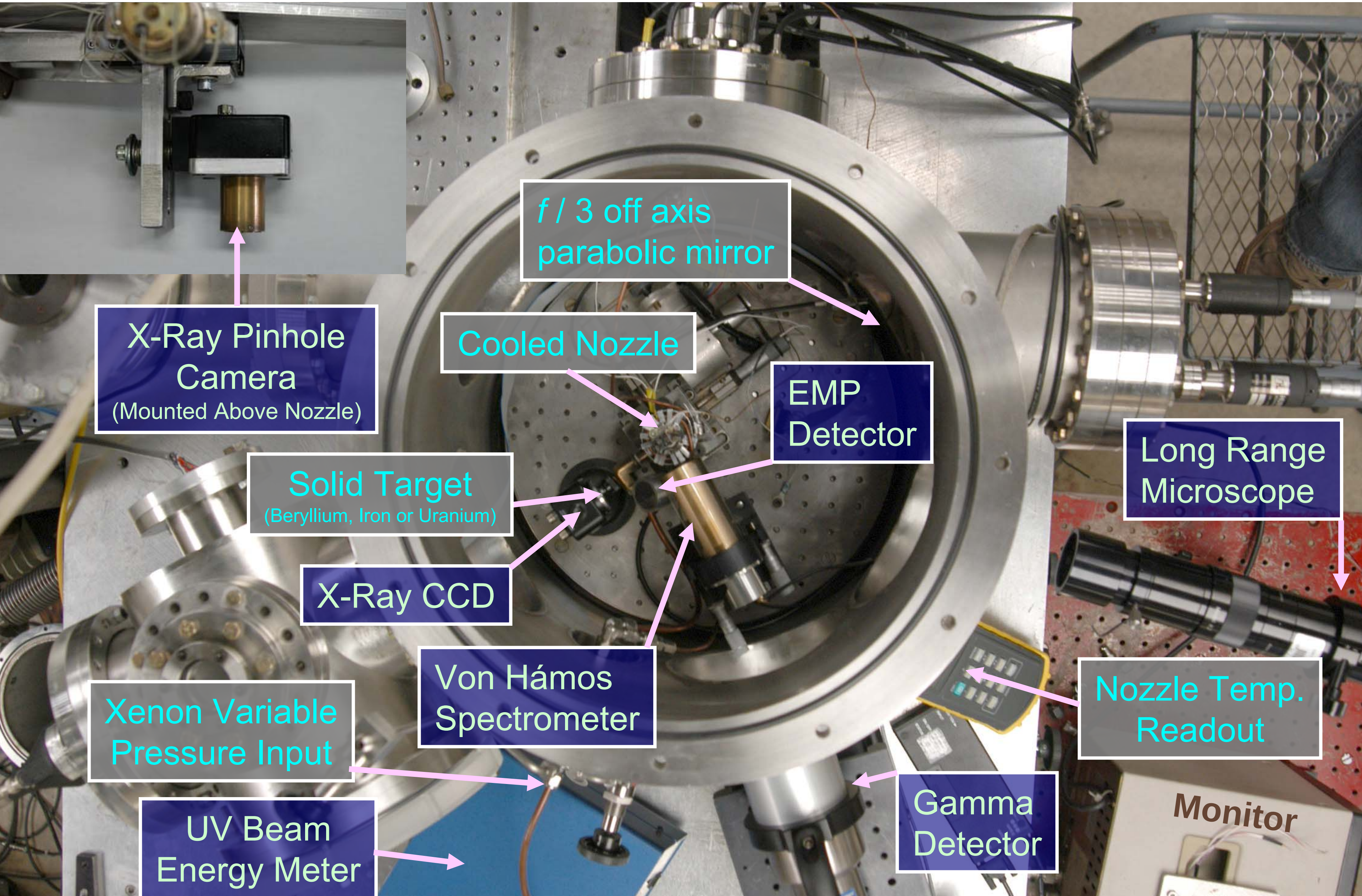
Chamber Layout



Chamber Setup

Input Variable

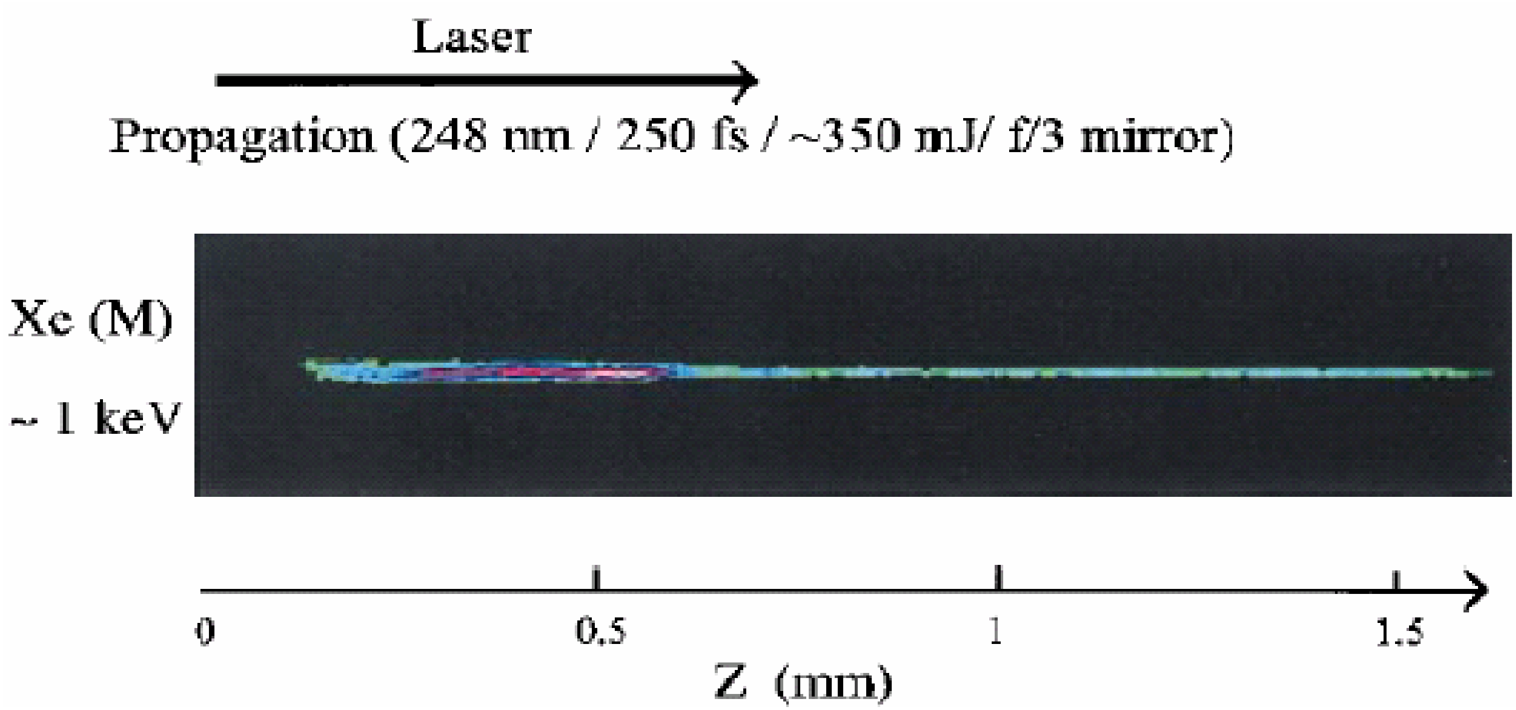
Experimental Data Source



Power Compression Concept Proven

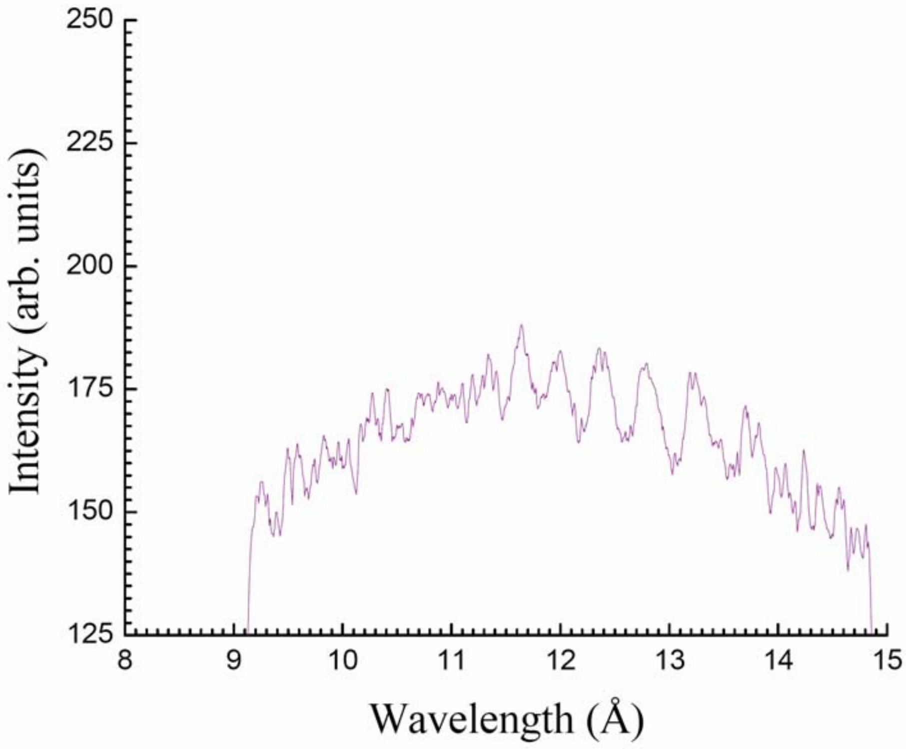
Xe(L)	$\lambda \cong 0.29$ nm	3d → 2p
Xe(M)	$\lambda \cong 1.26$ nm	4f → 3d

CHANNELED PROPAGATION KEY



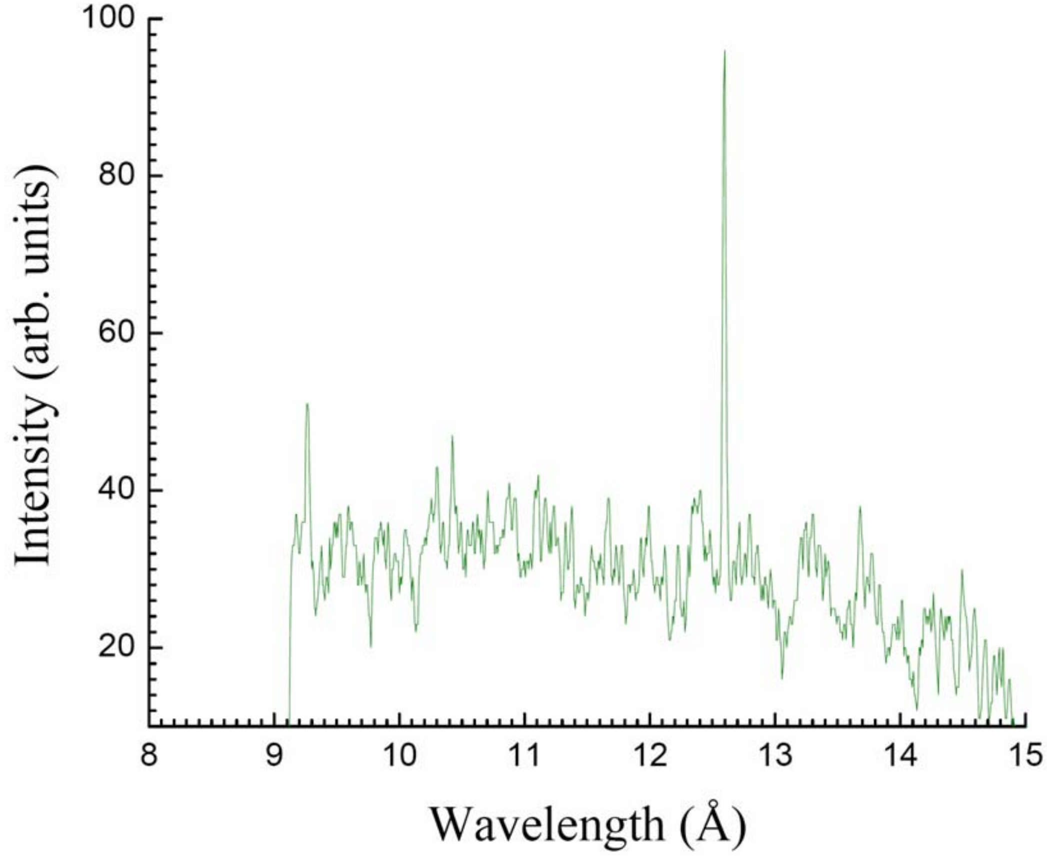
Xe(M) Spectrum in Transverse Direction from the Entrance Zone of the Stable Optimized Relativistic Channel

Film M05B



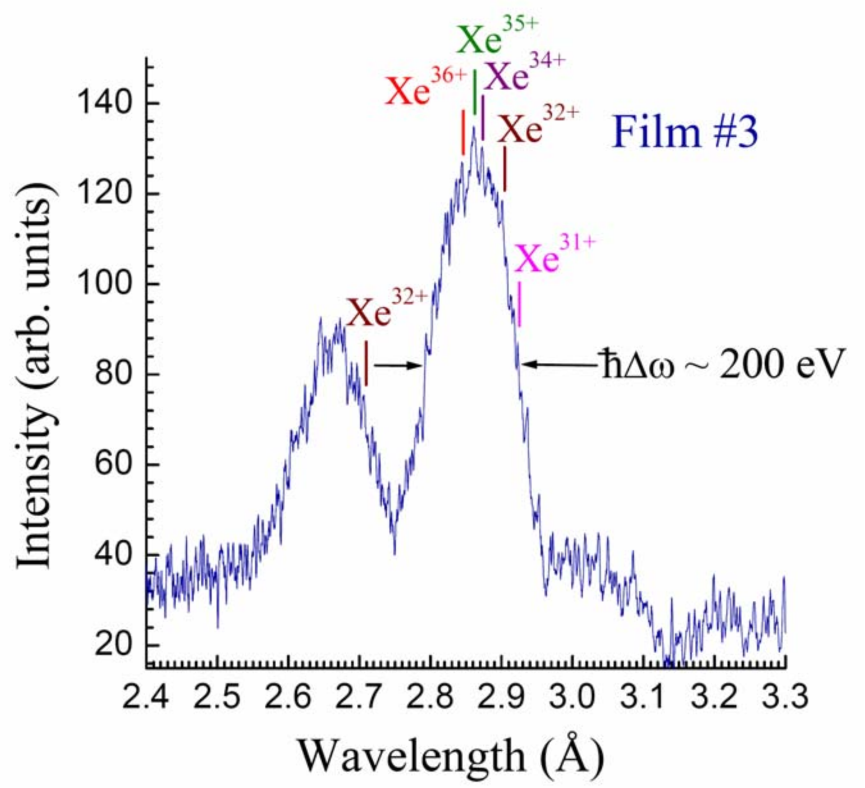
Amplified Xe(M) Spectrum in Forward Direction from Stable Optimized Relativistic Channel

Film M06A



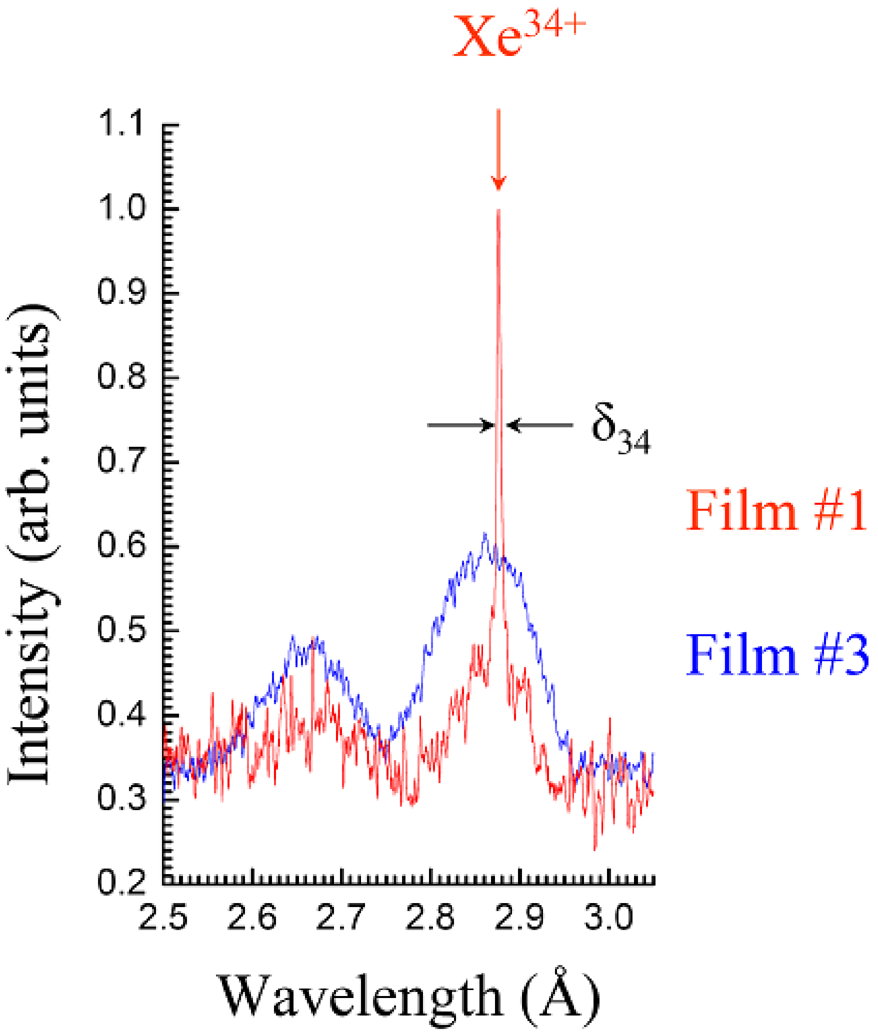
Xe(L) Spontaneous Emission Spectrum

$$2p^5 3d^n \rightarrow 2p^6 3d^{n-1}$$



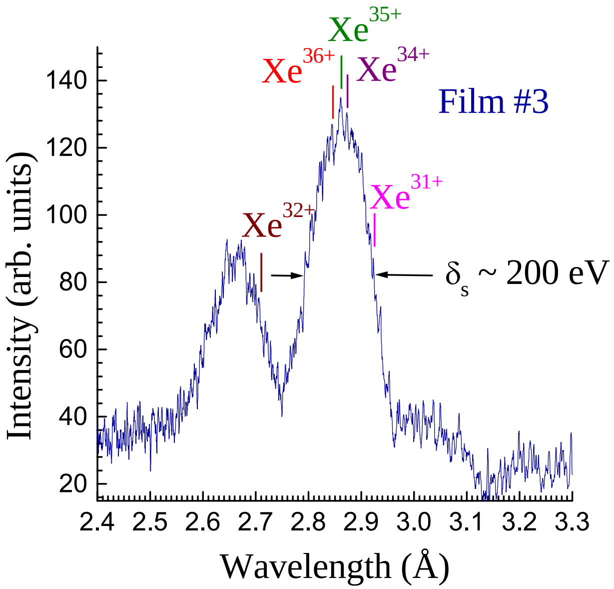
Fiq. (1). *Characteristic unamplified spontaneous emission profile of the Xe(L) 3d–2p hollow atom spectrum (film #3) produced from Xe clusters with femtosecond 248 nm excitation without plasma channel formation. The splitting between the major and minor lobes arises from the spin-orbit interaction of the 2p vacancy. The full width of the main feature is $\hbar\Delta\omega \sim 200$ eV. The positions of selected charge state transition arrays (Xe^{31+}, Xe^{32+}, Xe^{34+}, Xe^{35+}, and Xe^{36+}) are indicated.*

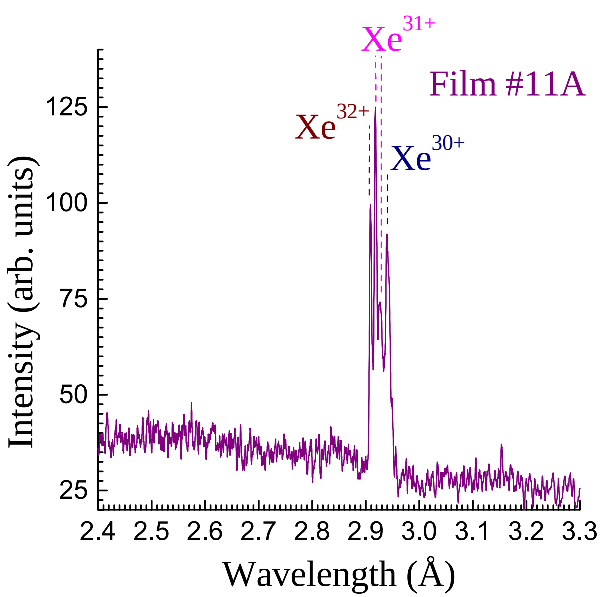
Xe^{34+} Line Amplification



Xe(L) Amplification

Xe(L)





Ruby

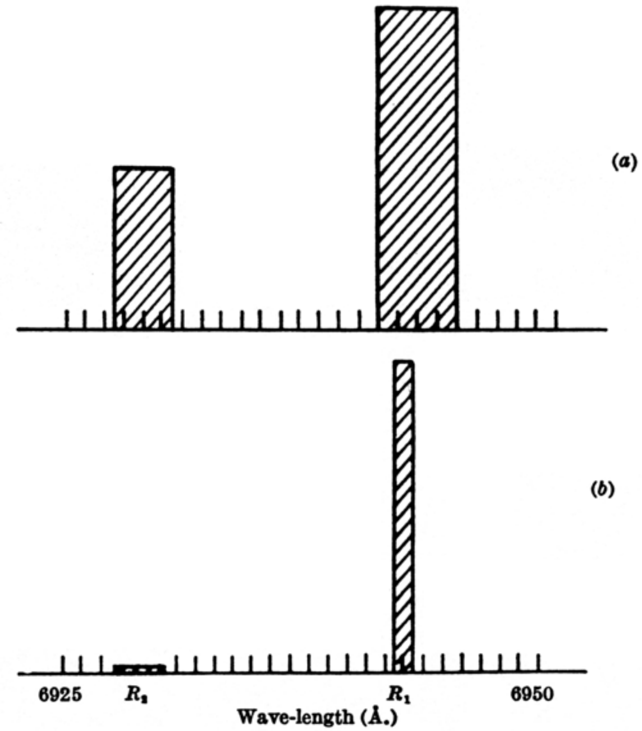


Fig. 2. Emission spectrum of ruby: *a*, low-power excitation; *b*, high-power excitation

the emission spectrum obtained under these conditions is shown in Fig. 2*b*. These results can be explained on the basis that negative temperatures were produced and regenerative amplification ensued. I expect, in principle, a considerably greater (~ 10^8) reduction in line width when mode selection techniques are used[1].

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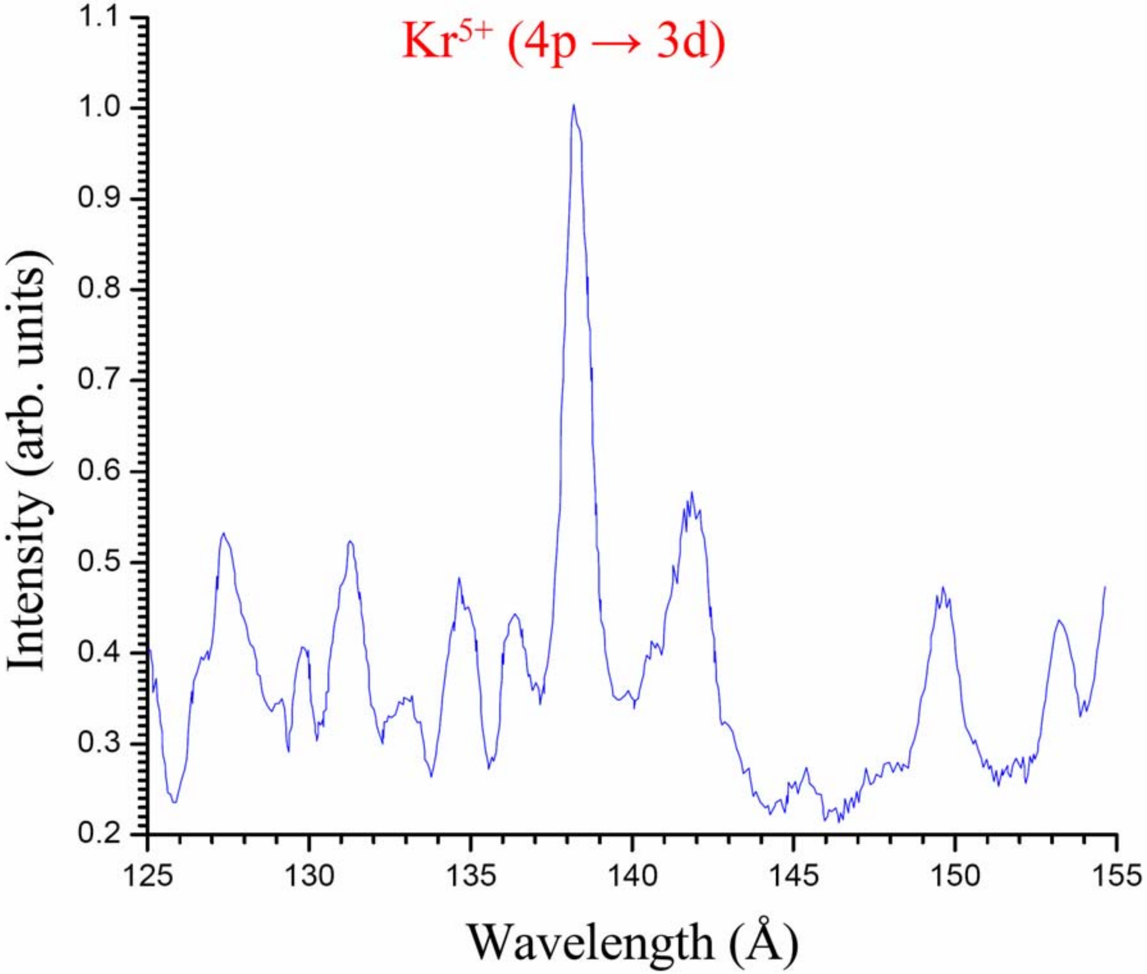
Kr(M) Lithography



Lithographic Source Requirements

POWER ~ 120 W	Exposure Needs
SPECTRAL CONTROL λ ~ 13.5 nm	Optics Available
SPATIAL CONTROL	Optimizes Efficiency

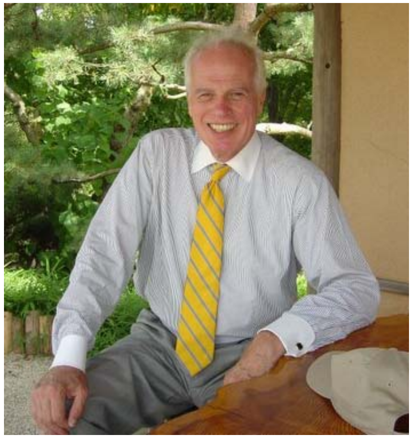
ALL CAN BE ACHIEVED WITH A WELL CONTROLLED STRONGLY AMPLIFYING MEDIUM

- AMPLIFICATION REQUIRES CONTROLLED POWER DENSITY AT HIGH LEVELS

- KEY PHYSICS → CONTROLLED POWER DENSITY

Optimal R & D Group
UIC / Ultrabeam Technologies, LLC

- World Leaders in X-ray Lasers
- Record Setting Wavelength of 2.71 Å with Xe(L)
- World's Brightest Light Source: $P/\lambda^2 \approx 10^{25}$ - 10^{26} $W/cm^2 \cdot sr$
- Combines University (UIC) and Industry (Ultrabeam Technologies LLC)
- Unique Laboratory Worldwide
- Proven Innovative Leadership



Conclusions

Predicted 13.5 nm Source Parameters

- Wavelength → $\lambda \sim 13.5$ nm
- Average Power → $P_{EUV} \approx 120$ W
- Debris – Load → Negligible
- **Reliability Given by Excimer Driver Technology**
- **Candidate Materials – Li, O, F, Xe**