QUALIFICATION OF DIODE FOIL MATERIALS FOR EXCIMER LASERS

R. G. Anderson, R. P. Shurter, E. A. Rose
Los Alamos National Laboratory
Los Alamos, New Mexico

The Aurora facility at Los Alamos National Laboratory uses KrF excimer lasers to produce 248 nm light for inertial confinement fusion applications. Diodes in each amplifier produce relativistic electron beams to pump a Kr-F-Ar gas mixture. A foil is necessary to separate the vacuum diode from the laser gas.

High tensile strength, high electron transmission, low ultraviolet reflectivity, and chemical compatibility with fluorine have been identified as requisite foil properties. Several different materials were acquired and tested for use as diode foils. Transmission and fluorine compatibility tests were performed using the Electron Gun Test Facility (EGTF) at Los Alamos. Off-line tests of tensile strength and reflectivity were performed.

Titanium foil, which is commonly used as a diode foil, was found to generate solid and gaseous fluoride compounds, some of which are highly reactive in contact with water vapor.

This work was supported by the Los Alamos National Laboratory and the U. S. Department of Energy under contract W-7405-ENG-36.

Introduction

The Aurora facility [1], [2] at Los Alamos National Laboratory uses KrF excimer lasers to produce 248 nm light for inertial confinement fusion applications. The final amplifier is a 10 kJ class device. The large amplifiers at Aurora have square laser beam apertures 20, 40, and 100 cm on a side. They are pumped with relativistic electron beams (600 to 700 kV, 650 ns pulse lengths). This method of pumping the gas avoids the nonuniformities inherent with large, electric discharge lasers. However, a foil is required to act as a barrier between the vacuum of the electron beam producing diode and the gas of the laser cavity, typically at 600 to 900 Torr pressure.

The diode foil must have several properties to be compatible with its use in a KrF excimer laser. We have identified and begun preliminary studies on four properties: high tensile strength, high electron transmission, fluorine compatibility, and low ultraviolet reflectivity. Each property is discussed in its own section below.

Our research into diode foils is part of an effort to improve upon the efficiency of transport of the electrons from the diode into the laser gas. All of the large amplifiers of Aurora require a foil support structure, commonly referred to as a "hibachi." This structure intersects a fraction of the electrons and prevents it from pumping the laser gas. We have determined that size reduction of this structure would be beneficial, specifically reducing the depth and count of ribs. A reduction in rib count requires higher strength foils than those now fielded to span the larger gaps between ribs [3]. The ultimate advance in foil/hibachi design is the elimination of the hibachi in favor of a single self-supporting foil which spans the full diode aperture.

Table 1 lists the foil types tested.

MATERIAL	THICKNESS	DESCRIPTION
A. Titanium	2 mil (51 μm)	Grade four commercially available foil
B. Titanium	.75 mil (19 μm)	Grade four commercially available foil
C. Beryllium-copper	1 mil (25 μm)	Be/Cu #25 1/2 hard condition
D. Aluminum	2.4 mil(61 μm)	2024-T81 alloy
E. Kevlar composite	6.5 mil (170 μm)	A 5 mil woven Kevlar/epoxy matrix heat laminated between .5 mil Ti foil and 1 mil Kapton
F. Graphite composite	11 mil (280 μm)	2 unidirectional prepreg graphite/epoxy matrices bidirectionally heat laminated between .5 mil Ti foil and 1 mil Kapton
G. Graphite composite	14.2 mil (360 μm)	A closely woven prepreg graphite matte heat laminated between .5 mil Ti foil and 1 mil Kapton
H. Graphite composite	6 mil (150 μm)	A (1/4") open weave graphite, epoxy loaded matrix heat laminated between .5 mil Ti and 1 mil Kapton

Table 1. Foil Types Tested

Tensile Strength

A high tensile strength foil is required to withstand the pressure differential between the gas in the laser cavity and the vacuum in the diode, typically 600 to 900 Torr. The foil must also be able to survive the shock loading caused by the rapidly heated gas immediately following the electron-beam pumping. This pressure rise is typically 400 to 600 Torr. A further requirement is that the foil not bow significantly. The allowed bowing distance is typically a few centimeters and is highly diode specific.

Tensile strength is a measure of the ultimate strength a material will withstand under tension before it fractures. The modulus of elasticity determines the amount of plastic deformation a material will experience under a load. The ideal foil would have a high tensile strength and a high modulus of elasticity. Candidate foils were tested in a fixture which applied a measured hydrostatic pressure to the foil mounted in a mock-up of a single hibachi opening. Failure pressures were recorded for each foil, and are graphed in Figure 1. The deformation distances noted were roughly gauged by visual comparison to a fixed scale. Foils were tested as received from the fabricator. Follow-up tests are planned for foils exposed to electron beams in the presence of fluorine-containing laser gas.

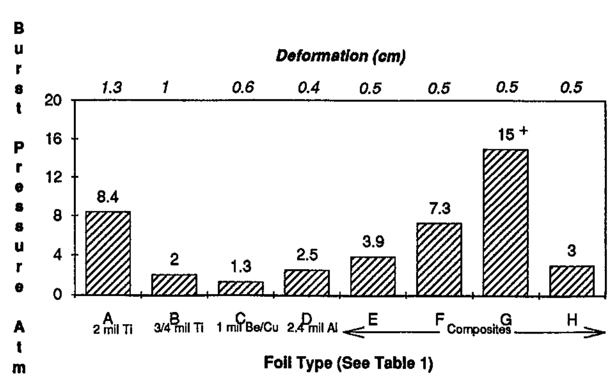

Figure 1. Hydrostatic Pressure Test

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **JUN 1989**	2. REPORT TYPE **N/A**	3. DATES COVERED **-**

4. TITLE AND SUBTITLE **Qualification Of Diode Foil Materials For Excimer Lasers**	5a. CONTRACT NUMBER
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Los Alamos National Laboratory Los Alamos, New Mexico**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S)
	11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release, distribution unlimited

13. SUPPLEMENTARY NOTES
See also ADM002371. 2013 IEEE Pulsed Power Conference, Digest of Technical Papers 1976-2013, and Abstracts of the 2013 IEEE International Conference on Plasma Science. Held in San Francisco, CA on 16-21 June 2013. U.S. Government or Federal Purpose Rights License.

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**SAR**	**3**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

Electron Transmission

The ideal foil would transmit all electrons incident upon it with no energy loss or angular scattering. Then all the energy of the electron pump beam would be available to the laser gas and the range of the electrons across the gas would not be degraded. However, electron loss, energy loss, and angular scattering do take place in foils. Our program investigated, in a qualitative manner, the transmission efficiency of candidate foils as a first attempt at discovering foils with promise.

Foils were characterized for electron transmission using the Electron Gun Test Facility (EGTF) at Los Alamos. The EGTF is capable of producing microsecond-duration electron beams in the 200 to 400 kV energy range. Current density is variable (tens of amps per square centimeter range) and the emitter is a Chang-profile, carbon-felt surface, 15 cm in diameter. There was an applied B_z field of 1400 Gauss.

Foils were mounted in a fixture in the vacuum volume as shown in Figure 2. The electron beam passed through a Rogowski coil, the foil, an aperture, another Rogowski coil, and was intercepted by a Faraday cup with a graphite collector. The electron beam current was measured with and without foils, using the Faraday cup, and the results were compared. A ratio of the current with foil to the current without foil was taken as the figure of merit for electron transmission of a particular foil. The ratio was only a rough measure of the foil transmission, however, since a portion of the scattered beam was not collected by the Faraday cup. (The Rogowski coils were used as current monitors to ensure shot-to-shot reproducibility.)

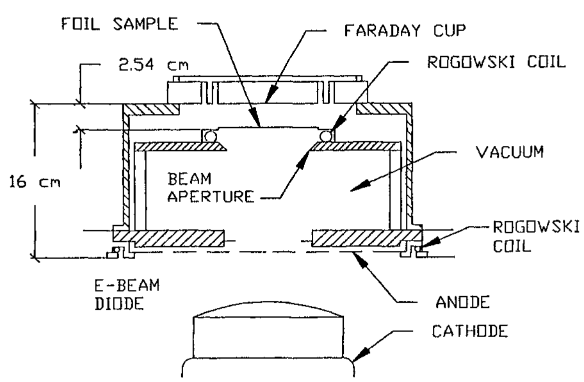

Figure 2. Test Setup For Beam Transmission.

Figure 3 shows this "figure of merit" for beam transmission for various foils.

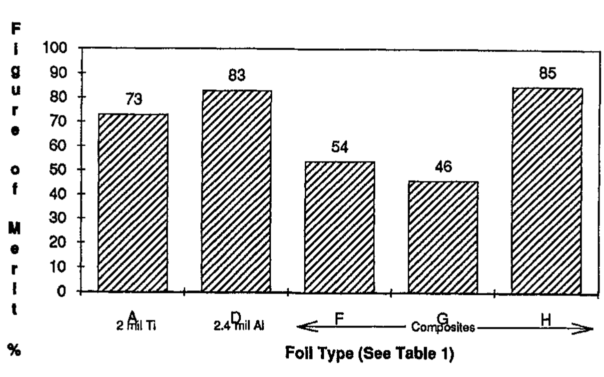

Figure 3. Electron Beam Transmission at 370 kV E-Beam Energy

Electron transmission figures do not, by themselves, determine whether a foil material transmits electrons effectively for laser gas pumping. Energy loss in the foil limits pumping efficiency, and angular scattering in the foil limits the range of the electrons across the laser cavity. Energy loss can be estimated from tables [4] or calculated with a Monte Carlo code. Moliere scattering calculations [5] can be used to estimate angular scattering. Low atomic number and low density yield foil materials with low angular scattering and energy loss.

Fluorine Compatibility

Compatibility of the foil with fluorine gas is essential for use in the KrF excimer lasers [6]. The foil must retain its integrity under exposure to fluorine gas at concentrations of less than 1% at laser operating pressures, and the foil must also not degrade under electron bombardment and subsequent attack by the electron-beam exposed laser gas. Another required property is that the foil not generate products which act as laser poisons or attack optical components.

EGTF was used to investigate foil properties under fluorine attack (Figure 4). Candidate foils were mounted in the single opening hibachi fixture mentioned above, and a test cell was mounted and filled with an 800 Torr laser gas mixture of 0.5% fluorine/99.5% argon. The foil was exposed to a 350 kV, 600 ns, 20 A cm^2 electron beam. Samples of gas were withdrawn for analysis before electron-beam exposure and after every five shots during the 15-shot run. The samples were analyzed with infrared and ultraviolet spectroscopy.

Four foils were tested: 2-mil titanium, 2-mil titanium with 1-micron gold coating, 2-mil titanium with 1-micron copper coating, and 2-mil Kapton with 1-micron copper coating. Coatings faced the laser gas mixture. (Gold and copper coatings were applied with a vacuum vapor deposition technique.)

The results of the analysis showed trace quantities of CF_4 in all samples due to fluorine reaction with hydrocarbon solvents and greases. There were also trace quantities of CO_2 in all samples, which most likely evolved from the elastomer o-rings in the test cell.

An HeNe laser was used to detect particulates generated by the foil and suspended in the laser gas. Collected particulates were analyzed with X-ray photoelectron spectroscopy (XPS).

Titanium foil without a coating generates a white powder when exposed to an electron beam in the presence of 0.5% fluorine. The

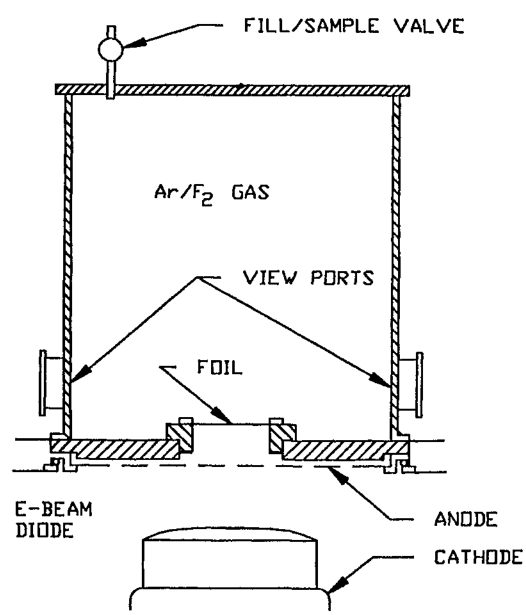

Figure 4. Test Setup For Gas Chemistry

powder is observed to form as a suspension in the fluorine/argon gas mixture. The powder collects on surfaces and, upon exposure to air, becomes a clear, sticky fluid. When placed in vacuum, it returns to a white, solid form. Our hypothesis is that TiO_2 is vaporized from the foil surface, reacts with fluorine gas to form TiF_4, and condenses to produce a powder. The liquid, formed upon exposure to air, is a hydrated form. The liquid has been observed to etch optical components upon which it was smeared.

Ultraviolet Reflectivity

Foils with low reflectivity in the ultraviolet are desirable to minimize parasitics and amplified-spontaneous-emission (ASE) effects within KrF laser amplifier cavities. High reflectivity foils act as mirrors and promote lasing modes which can compete with the incident laser beam for energy and can also produce optical component damage.

Candidate foils materials were tested for UV reflectivity with a Cary Model 2300 double pass analyzer (Figure 5). Samples were prepared by vapor deposition of one micron of foil material on a sapphire substrate. This deposition technique provided a more uniform surface quality for all samples and allowed decoupling of the reflectivity measurement from the peculiarities of fabrication of particular foils. The samples were illuminated with a variable wavelength, specular light source in a double-pass configuration. Reflectivity of samples was compared with a calibrated aluminum reference to get an absolute reflectivity.

Figure 6 shows the results of the reflectivity measurements. Samples were exposed to 0.5% fluorine/99.5% argon at 600 Torr for eighteen

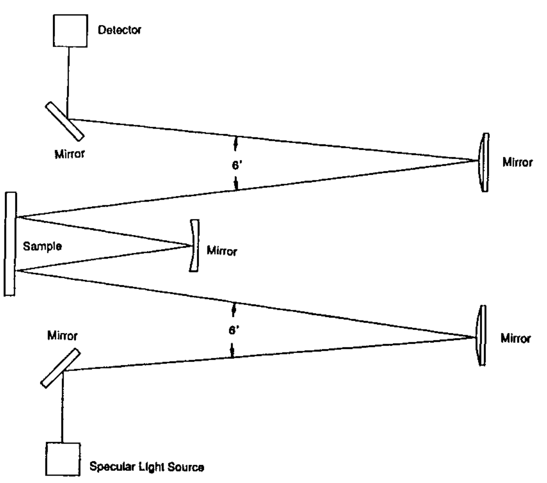

Figure 5. Double Pass Analyzer Test Setup

hours to approximate the conditions found in the laser amplifier. Reflectivity measurements were made at wavelengths from 220 to 300 nm. The data shown in Figure 6 is for 248 nm (KrF).

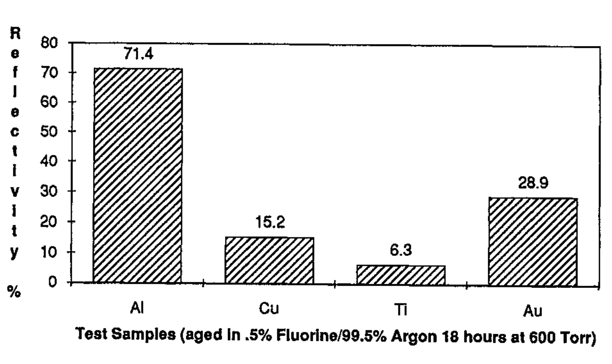

Figure 6. Absolute Reflectivity at 248 nm

Conclusion

We have begun a program at Los Alamos National Laboratory to develop foils for use in electron-beam pumped KrF excimer lasers. Several techniques have been applied to the task of diagnosing foil strength, electron transmission, UV reflectivity, and fluorine compatibility. These techniques will be refined in the future to generate data that is more quantitative in nature.

We are particularly interested in pursuing the development of composite foils, which use graphite fibers. Graphite fibers are a high-tensile-strength material which have low density and atomic number. The ability to vapor deposit thin layers of fluorine-compatible, low UV reflectance metals allows a wider choice of base foil materials and, in particular, allows continued use of titanium foils.

In the short term, the capabilities of this foil development program are being applied to the Aurora project. Titanium foils are being replaced with more fluorine-compatible materials. Stronger foils are being developed to allow the installation of more transmissive hibachi structures. This will increase the efficiency of electron-beam pumping of the KrF excimer laser amplifiers.

In the long term, the foil development program will facilitate design of the next generation of large, efficient KrF lasers for inertial confinement fusion applications.

Acknowledgements

We would like to extend our appreciation to T. Bell and J. Umphres of CLS-7, Los Alamos National Laboratory, for experimental support on the Electron Gun Test Facility; H. Garcia and M. Salopek of CLS-7, Los Alamos National Laboratory, for gas analysis; P. Gobby, E. Eaton, C. Sadler, C. Hosford, of MST-7, Los Alamos National Laboratory, for technical support in the fabrication of test materials; and to T. Johnson and G. Gallegos of CLS-6 for the data on materials reflectivity.

References

[1] L. A. Rosocha, J. A. Hanlon, J. McLeod, M. Kang, B. L. Kortegaard, M. D. Burrows, and P. S. Bowling, "Aurora Multi-kilojoule KrF Laser System Prototype for Inertial Confinement Fusion," Fusion Technology, 11, 497 (1987).

[2] L. A. Rosocha and K. B. Riepe, "Electron-Beam Sources for Pumping Large Aperture KrF Lasers," Fusion Technology, 11, 576 (1987).

[3] M. Kang, B. Weinstein, and E. Rose, "An Improved Hibachi Support Structure for Electron-Beam Diode Foils," Proc. 7th IEEE Pulsed Power Conf., Monterey, CA (1989).

[4] L. Pages, E. Bertel, H. Joffre, and L. Sklavenitis, "Energy Loss, Range, and Bremsstrahlung Yield for 10-keV to 100-MeV Electrons in Various Elements and Chemical Compounds," Atomic Data 4, 1-127 (1972).

[5] H. Bethe, "Moliere's Theory of Multiple Scattering," Physical Review 89, 1256-1266 (1953).

[6] R. G. Anderson and R. A. Tennant, "Evaluation of KrF Electron-Beam Foil Materials," CLEO 11, TUJ44 (1989).