PREPARED FOR THE U.S. DEPARTMENT OF ENERGY,
UNDER CONTRACT DE-AC02-76CH03073

PPPL-3900
UC-70

PPPL-3900

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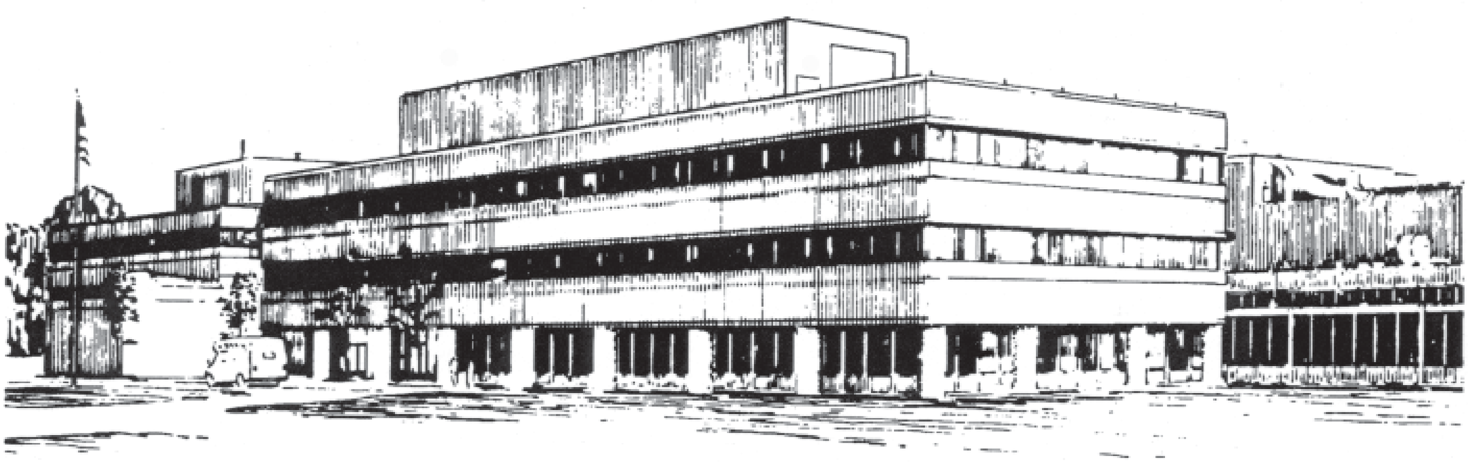
November 2003

PPPL
PRINCETON PLASMA
PHYSICS LABORATORY



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The Development of a Hibachi Window for Electron Beam Transmission in a KrF Laser

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Abstract **- In support of Inertial Fusion Energy (IFE) a 150 μm thick silicon (Si) wafer coated on one side with a 1.2 μm nanocrystalline diamond foil is being fabricated as an electron beam transmission (hibachi) window for use in KrF lasers. The hibachi window separates the lasing medium from the electron beam source while allowing the electron beam to pass through. The hibachi window must be capable of withstanding the challenging environment presented in the lasing chamber, which include: fluorine gas, delta pressure > 2 atm @ 5 Hz, and a high heat flux due to the transmission of electrons passing through the foil. Tests at NRL / Electra and at PPPL have shown that a device employing these novel components in the stated configuration provide for a robust hibachi window with structural integrity.**

I. Introduction

The Princeton Plasma Physics Laboratory (PPPL) in collaboration with The Naval Research Laboratory (NRL) is currently investigating the use of single crystal silicon (<100>) and nanocrystalline diamond for use as an electron beam (hibachi) transmission window in a Krypton Fluoride (KrF) excimer laser. The primary function of the hibachi window is to separate the excimer gas from the dual coaxial double-pass field-emission diodes and is an integral component of KrF lasers for use in inertial fusion energy (IFE) energy devices [1]. The hibachi window gets its name from geometric similarities in the frames (that support the electron beam transmission windows in the lasing cell) with a hibachi grid configuration. The frames are situated close in proximity and operate at high temperatures.

The silicon / nanocrystalline diamond window must be thin enough to allow electron beam transmission > 80 % at energies ranging from 150 KeV to 750 KeVwhile maintaining full structural integrity in a challenging and chemically hostile environment. Pressure differentials on the window can be as high as 2.3 atm with a pulse rate of @ 5 Hz and an operating temperature > 350 C. In addition, fluorine gas, a highly reactive oxidizing agent, is a component (0.5 % diatomic fluorine) of the lasing gas medium, and is in constant contact with the high pressure side of the hibachi window.
In addition to the operational challenges the window must be fabricated and mounted in a fashion which supports economical construction and relative ease of change out. The window is required to support long continuos duty operating cycles that can include 10^{6} pulses.

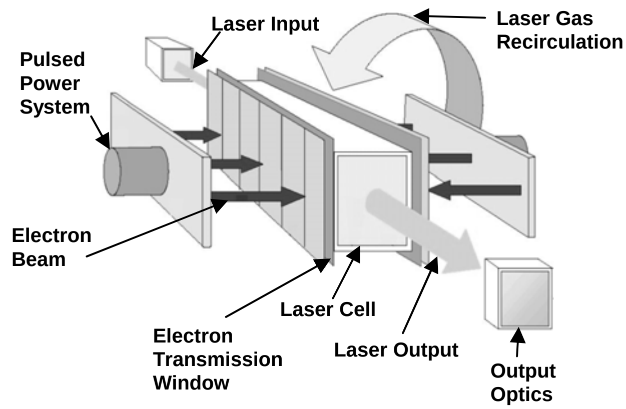

Figure 1. Key Components of a KrF Excimer Laser

II. Hibachi Window Materials

Silicon, a low Z material provides for an excellent candidate material for a electron beam transmission window. Single crystal Si wafers which exhibit low torsional and thermal stress under applied loading provide a high failure resistance and a relatively high Young's modulus of ~ 190 Gpa while supporting a high percentage of electron beam transmission in the 150 Kev to 750 KeV range [2,3]. A unique challenge in the design of a silicon based hibachi window is making it chemically resistant to the fluorine gas in the laser cell. Fluorine which has the highest standard oxidation potential (+2.866 eV) of all the elements is extremely corrosive to silicon [4]. To eliminate the deleterious effect of fluorine gas with silicon a 1.2 μm thick nanocrystalline diamond foil is fixed to the high pressure side of the hibachi window. This nanocrystalline diamond passivation layer provides for a excellent chemical shield of the silicon window and exhibits no discernable attenuation of electron beam transmission. The nanocrystalline diamond which is applied by chemical vapor deposition (CVD) is strongly bound to the silicon substrate and conforms well with the operational parameters that the window is subjected to. Extensive cycling of the described silicon/diamond foil (figure 2) has resulted in no delamination of the nanocrystalline diamond coating from the silicon wafer. It has been demonstrated that after > 8,000 test cycles at 5 Hz the window was observed to have maintained its full structural integrity.

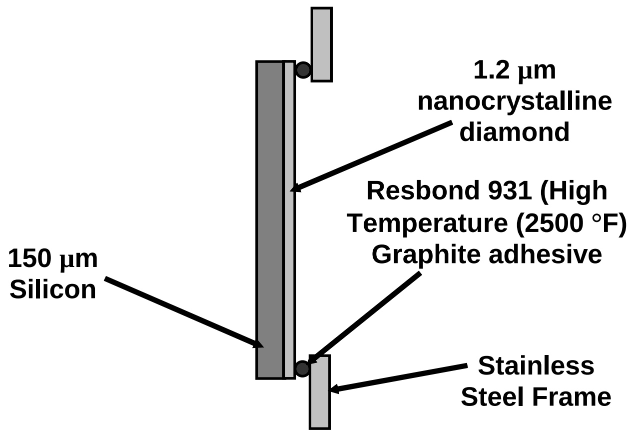

Figure 2. Silicon/Diamond foil configuration

The window was tested under various conditions which included testing on an engineered test stand at PPPL which reproduced many of the conditions found inside the Electra lasing chamber. The test stand provided an economical means for testing different configurations as to optimize the design of the window. Various geometries were tested which included several earlier designs that incorporated ribs across a thinner silicon pane area which resembled a standard nine (9) pane conventional window frame. After multiple test runs it was determined that a single 150 µm thick silicon wafer, 25 mm in diameter, coated on the high pressure side (the side facing the gas) was the most economical and structurally sound configuration for the required application. In addition, this configuration provided for a relatively inexpensive window which cost <$500. Earlier configurations with etched ribs cost as much as $10,000 for single prototype units. This configuration was further deemed viable after it was determined that not only did the nanocrystalline diamond not delaminate from the silicon wafer, but that it would also deflect under delta P cycling while maintaining full structural integrity as illustrated in figure 3.

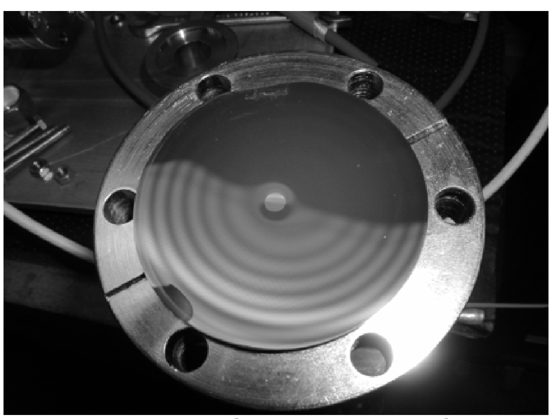

Figure 3. Diamond foil on silicon wafer at 5 torr

III. Testing at Electra

During September of 2003 several windows of the stated configuration were taken to the NRL laboratory in Washington D.C. for testing at Electra. Electra is the NRL test stand laser for research performed in the area of IFE. The windows were mounted in a stainless steel holder which was fitted to the barrier frame which separates the vacuum side, from which electron beams are accelerated, to the high pressure gas lasing chamber. The windows were subjected to multiple electron beam shots in single, burst, and multiple Hz repetition rates. The main purpose of these tests was to determine the structural integrity of the window and best mounting configuration in the Electra lasing cell. It was observed that a window mounted with a high temperature (2500 °F) graphite adhesive performed to full satisfaction. The window maintained full structural integrity while providing > 80% electron beam transmission. In addition, the window was subjected to temperatures > 350 °C during the burst and multiple Hz repetition rate testing. As a result of these trials it was decided that a multiple hibachi window frame should be fabricated employing a similar silicon nanocrystalline diamond foil geometry for further testing at Electra.

IV. Path Forward

As a result of successful test stand at PPPL and field tests at Electra, PPPL in collaboration with NRL is currently in the process of designing a multiple window (40 windows) hibachi frame for testing and deployment. Preliminary and follow up testing have shown that such a device is viable and can provide for the efficient transmission of electrons in KrF lasers. In addition, emphasis shall be placed on ease of window change out, economy, and operational considerations.

V. Conclusion

The fabrication of a electron beam transmission (hibachi) window employing novel materials is achievable, economical, and practical. The use of a single silicon crystal coated with a thin (1.2 µm) layer of nanocrystalline diamond provides for a robust device which can be used for long duty cycles in KrF lasers in support of IFE development. Test stand and field testing of the device has shown that the window can perform under various environmental conditions which include rapid delta P cycling (at 5 Hz), exposure to corrosive gas (fluorine), high temperature (> 350 °C) thus providing a barrier which separates vacuum from pressures up to 2.3 atmospheres. The window has been successful in various tests and supports a >80% transmission of electrons into the lasing gas chamber.

VI. ACKNOWLEDGMENT

This work is supported by The Naval Research Laboratory (NRL) in collaboration with The Princeton Plasma Physics Laboratory (PPPL).

VII. References

[1] J.D. Sethian, M. Friedman, M.Myers, F.Hegeler. S. Swanekamp, T. Albert, "The Electra Hibachi-Objectives, Status, Plans, and Directions" , Naval Research Laboratory, March 20, 2001

[2] P. Rai-Choudhury, "Handbook of Microlithography, Micromachining, and Microfabrication" , SPIE Optical Engineering Press, 1997

[3] K.Petersen, "Silicon as a Mechanical Material" , Proceedings of the IEEE, Vol. 70 No. 5, 1982

[4] "Handbook of Chemistry and Physics" , D.R. Lide, Editor -In-Chief, 80th ed., CRC Press, 1999 - 2000

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07/07/03

The Princeton Plasma Physics Laboratory is operated by Princeton University under contract with the U.S. Department of Energy.

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