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2×1 prototype plasma-electrode Pockels cell (PEPC) for the National Ignition Facility

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ABSTRACT

A large aperture optical switch based on plasma electrode Pockels cell (PEPC) technology is an integral part of the National Ignition Facility (NIF) laser design. This optical switch will trap the input optical pulse in the NIF amplifier cavity for four gain passes and then switch the high-energy output optical pulse out of the cavity. The switch will consist of arrays of plasma electrode Pockels cells working in conjunction with thin-film, Brewster's angle polarizers.

The 192 beams in the NIF will be arranged in 4×2 bundles. To meet the required beam-to-beam spacing within each bundle, we have proposed a NIF PEPC design based on a 4×1 mechanical module (column) which is in turn comprised of two electrically independent 2×1 PEPC units.

In this paper, we report on the design a single 2×1 prototype module and experimental tests of important design issues using our single, 32 cm aperture PEPC prototype. The purpose the 2×1 prototype is to prove the viability of a 2×1 PEPC and to act as an engineering test bed for the NIF PEPC design.

1. INTRODUCTION

The main laser amplifier in the National Ignition Facility (NIF) will be a four-pass design that employs active optical switching. The switch traps an optical pulse in the cavity and then switches the pulse out of the cavity after four gain passes. The optical switch for this consists of a Pockels cell and a Brewster's angle polarizer for each of the 192 beams in NIF. We design the switch such that when the Pockels cell is on (biased to the half-wave voltage) it rotates the beam polarization 90 degrees so the light passes through the polarizer. In this state, the laser cavity is closed and the optical pulse multipasses. When the Pockels cell is off, it does not rotate the beam polarization so the optical pulse reflects from the polarizer and out of the cavity.

Since the beam size for NIF is 40 cm × 40 cm, the NIF optical switch requires a Pockels cell with a 40 cm × 40 cm aperture. We cannot scale commercially available ring-electrode Pockels cells to this size and shape. We used the Beamlet laser, constructed at Lawrence Livermore National Laboratory in 1994, to demonstrate that we could utilize a large-aperture Pockels cell effectively in a high-energy laser by using a plasma-electrode Pockels cell (PEPC)¹. In a PEPC, both sides of a thin (1cm) potassium di-hydrogen phosphate (KDP) crystal are covered with plasmas formed by electrical discharge. These plasmas act as transparent, highly conductive electrodes that allow uniform application of voltage across the crystal by an external high-voltage pulse generator.

Fig. 1. NIF 4×1 PEPC column

An additional constraint posed by the NIF design is that the beam apertures are tightly packed into arrays (bundles) four high by two wide (4×2). We cannot directly apply the Beamlet PEPC design to the NIF because an array of such PEPCs would not meet the required inter-beam spacing. To solve this problem, the PEPCs for NIF will be arranged in columns four high by one wide (4×1) as shown in Figure 1. However, each such column will be comprised electrically of two independent 2×1 PEPCs. In each 2×1 , the plasma electrode must span two KDP crystals, and the external high-voltage pulse generators must uniformly charge two crystals in parallel. To test the efficacy of this approach, we have designed and are in the process of assembling a 2×1 PEPC prototype with actual NIF size apertures and inter-beam spacing. In this paper, we describe the design of this device and present results of experiments we performed to pre-test some of the important design features and issues.

2. 2×1 DESIGN DESCRIPTION

Figure 2 shows an engineering drawing of our 2×1 PEPC. It is comprised of anodized aluminum housings on either side of a glass midplane into which a pair of KDP crystals are potted with silicone elastomer. Anode electrodes are mounted on one side of the cell while cathode electrodes are mounted on the other. We form the plasma discharges between these anode-cathode pairs. A turbomolecular-drag pump evacuates the cell, and the pumping ports are concentric with the anodes. The cathodes will be either planar magnetrons or hollow cathodes. We have demonstrated adequate performance with both types of cathodes. Fused silica windows bound the vacuum region in which we form the plasma electrodes. The windows fit into the housing in such a way as to form a uniform width and relatively narrow (5 cm) plasma channel. In work described elsewhere², we determined that plasma edge density increases as plasma width decreases and that higher edge density facilitates rapid and uniform charging (or discharging) of the KDP crystal.

The use of aluminum for the housings is an important change from previous designs. We fabricated both the Beamlet and the 32 cm prototype PEPCs from ultra-high molecular weight polyethylene (UHMW). As a dielectric material, UHMW provided unequivocal insulation for both the plasma discharges and the high-voltage switch-pulse. However, problems with material strength and fabrication accuracy caused us to consider other materials for the NIF design. We considered glass or ceramic which would also provide unequivocal insulation. However, initial bids for a 2×1 device were exceptionally expensive and scaling to a full 4×1 looked doubtful. Aluminum provides many important mechanical and cost advantages but poses a problem of how to keep the plasma discharges from being shorted out by the housings.

Fig. 2. Engineering model of a 2×1 PEPC now in construction at LLNL.

3. HOUSING MATERIAL AND INSULATION

To solve the housing insulation problem, we explored the use of coatings to insulate the plasma from the aluminum housings. Our baseline approach is to insulate the housing with a hard anodizing coating. While such a coating is inexpensive and mechanically durable, it does not exhibit high dielectric strength (it typically breaks down at about 1 kV). However, we have performed experiments that show our plasma discharges are not disrupted by anodized aluminum boundaries as long as the underlying aluminum substrate is biased at the proper potential. Figure 3 shows a schematic diagram of the plasma discharge circuit. The cathode is the most negative potential. The segmented anodes are more positive by the plasma voltage drop (600

Fig. 3. Plasma discharge circuit diagram showing various potential bias points.

volts) and the anode bus is even more positive (by several hundred volts) due to the voltage drop across the ballast resistors. We tested housing bias at the cathode, anode, and anode bus potentials. We also tested the floating potential by not connecting the test plates to anything. While the plasma is not grossly disrupted with the housings biased at cathode, anode or floating potential, we discovered the plasma is apparently repelled from the side boundaries as the housing bias becomes more negative. We believe this is due to an $\mathbf{E} \times \mathbf{B}$ drift of plasma away from the anode side corners. The electric field, $\mathbf{E}$, comes from the sheath voltage near the walls while the $\mathbf{B}$ comes from the external return current and plasma current. With the housings at cathode potential, the plasma is sufficiently repelled from the sides that uniform charging of the crystal is compromised. With the housings at floating potential, the effect is reduced but still observable. With the housings at anode or anode bus potential, plasma repulsion from the sides is eliminated. Note that with housing made from dielectric materials, the boundary must be at the floating potential. Our experiments indicate that with anode bias, metallic housings actually provide better plasma uniformity than dielectric housings.

To test whether anodizing provided sufficient insulation, we intentionally damaged our test boundaries both mechanically and electrically. Even with a heavily damaged coating, we did not observe a gross plasma disruption with anode bias. However, with our test boundaries biased at the more positive anode bus voltage, the discharge arced to the damaged spots and became highly nonuniform.

4. CONCLUSION

In this paper, we described our plans to implement plasma-electrode Pockels cells in the NIF laser. We will construct the NIF Pockels cells in vertical columns four apertures high and one wide. However, each of these 4×1 columns will consist of a pair of electrically independent 2×1 PEPCs. We are presently building a prototype 2×1 PEPC with full size NIF apertures. This 2×1 will contain many new design features that are a result of our continuing PEPC development program. Of particular importance is that we have changed from our previous use of UHMW polyethylene as the structural

material and now plan to use anodized aluminum. We have shown that anodizing provided sufficient insulation as long we bias the underlying aluminum at the anode potential.

5. ACKNOWLEDGMENTS

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6. REFERENCES

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