EXPERIENCE WITH FIBER-BASED DRIVE LASERS AT CEBAF-JEFFERSON LAB AND HIGH CURRENT LIFETIME STUDIES *

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Abstract

CEBAF/Jefferson Lab operates at relatively low average beam current compared to most energy recovering linacs, however the lessons learned at CEBAF with DC high voltage GaAs photoguns might be useful for the ERL community, particularly in the areas of fiber-based drive lasers and high current lifetime studies.

INTRODUCTION

The Continuous Electron Beam Accelerator Facility (CEBAF) at Jefferson Lab supports nuclear physics research by providing spin polarized electrons to three experimental halls using a DC high voltage GaAs photogun. Average beam current at CEBAF is typically ~ 100uA, considerably lower than required by most ERL facilities, however recent experience with fiber-based drive lasers might be interesting to the ERL community as it seems likely this technology can be scaled to considerably higher power. In addition, experiments were conducted at a dedicated gun test stand, to explore gun lifetime dependence on laser spot size at average beam currents up to 10mA. These tests indicate lifetime enhancement with larger drive laser spots, consistent with a simple prediction based on photocathode decay associated with ion backbombardment.

FIBER-BASED DRIVE LASER

For years, three modelocked Ti-Sapphire lasers were used to drive the CEBAF DC high voltage GaAs photoguns, one laser for each experimental hall. These commercial lasers from Time Bandwidth Products rely on passive modelocking using a semiconductor saturable absorber mirror (SESAM) to produce RF-pulsed light at 499 MHz. Sophisticated feedback electronics provide a means to lock the pulse train to an external reference frequency (i.e., the accelerator) with integrated phase noise less than 1ps. Unfortunately, sustained reliable phase-locked operation required maintenance by laboratory staff typically once per week, to realign the laser cavity mirrors to minimize oscillation at higher order spatial modes and/or to obtain oscillation at new locations on the semiconductor saturable absorber mirror that sometimes became damaged via inadvertent Q-switching. Laser maintenance resulted in ~ 120 hours of accelerator downtime per year, approximately twice the CEBAF goal.

To minimize accelerator downtime, a fiber-based laser system was constructed [1]. The key advantage of the fiber-based laser is that optical pulses are created via gain-switching, a purely electrical technique independent of laser cavity length. Feedback loops are not required to maintain phase-lock of the optical pulse train to the accelerator RF: the phase noise and stability of the laser are set by the fidelity of the RF source used to drive the diode seed laser (described below). Fiber-based laser systems have other advantages, in particular, fiber-based components do not need to be cleaned or aligned: simply connect fiber-coupled components together and apply electrical current to obtain many Watts of power at 1560 nm. Granted, this light must be frequency-doubled to be useful for GaAs photoguns, but it is fairly easy to obtain 40% doubling efficiency without sophisticated mounts or hours of alignment. Moreover, the fiber-based drive laser described below actually produces four times the optical power provided by the modelocked Ti-Sapphire lasers used previously.

System Description

The fiber-based drive laser has a master-oscillator power-amplifier configuration consisting of three main components; the gain-switched fiber-coupled diode seed laser, the ErYb-doped fiber amplifier and the periodically-poled lithium niobate (PPLN) frequency-doubler (Fig.1). Gain switched diode lasers produce optical pulses when biased near threshold and driven with ~ 1W of RF power using a bias network. The frequency of the optical pulse train follows that of the applied RF and can be varied over a wide range (0.1 to 3 GHz). The inexpensive DFB diode laser purchased from Thor Labs produced 0.5 mW average output power at 499 MHz and the optical pulsewidth was ~ 40ps. Diode lasers typically produce pulsewidths between 30 and 100ps, a value set mostly by the laser cavity length (and photon lifetime). The output power of a gain-switched diode laser scales loosely with duty factor.

The fiber pigtail of the seed laser (single mode, polarization maintaining with FC/APC connector) was attached to the mated input connector of the commercial ErYb-doped fiber amplifier [2], a “turn-key” device without user serviceable components that provides up to 38dBm gain and maximum output power of 5 W at 1560 nm for input power within the range of 0.1 to 1mW (-10 to 0 dBm) between 1545 and 1565nm. A vendor-supplied collimating lens attached to the single-mode, polarization-preserving output fiber produces an output beam with ~ 2mm diameter (FWHM).

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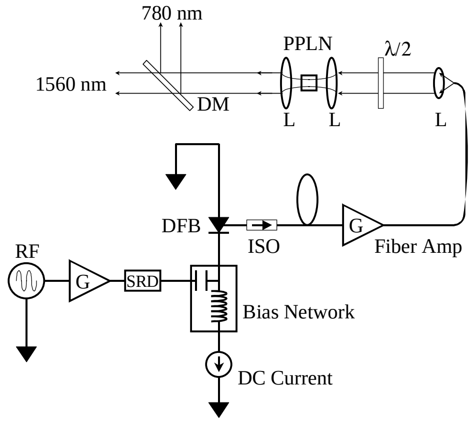

Figure 1. Schematic of the fiber-based laser system. DFB, distributed feedback Bragg reflector diode laser; ISO, fiber isolator; SRD, step recovery diode; L, lens; PPLN, periodically poled lithium niobate frequency doubling crystal; DM, dichroic mirror.

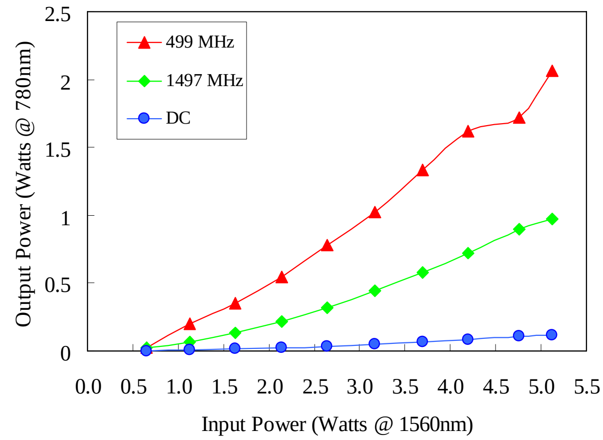

Figure 2: Output power of the fiber-based laser system at 780 nm versus input power from the seeded ErYb-doped fiber amplifier at 1560 nm.

The beam from the fiber amplifier was directed into a temperature tuned periodically poled lithium niobate (PPLN) crystal 10 mm long. A lens with 30 mm focal length provided a calculated beamwaist of ~ 28μm at the center of the PPLN crystal and a Rayleigh range of ~ 1.6mm. Efficient frequency-doubling required adjustment of the trajectory of the 1560 nm light through the PPLN crystal, proper orientation of the input linear polarization using the halfwave plate upstream of the PPLN crystal, and temperature tuning of the PPLN crystal to obtain optimum phase matching for the two light beams at wavelengths 1560 nm and 780 nm. The light that leaves the PPLN crystal was collimated using another 30 mm focal length lens. A dichroic mirror reflects the useful 780 nm light and passes residual 1560 nm light which is dumped.

The performance of the system is shown in Figure 2, where output power at 780 nm is plotted versus PPLN input power at 1560 nm for three input conditions; DC light and rf-pulsed light at 499 MHz and 1497 MHz. The non-linear frequency-doubling process favors high peak power, which of the three conditions tested corresponds to 499 MHz. The maximum conversion efficiency was ~ 40% (P_{out}/P_{in}). Initially there was concern that the spectral bandwidth of the gain-switched seed light (~ 2 nm) would be too wide to obtain high conversion efficiency but 2W average output power at 780 nm and 499 MHz clearly exceeded our design goal of 500mW, the output power of the modelocked Ti-Sapphire drive lasers we hoped to replace.

Shortly after construction, the fiber-based drive laser was installed at CEBAF, where it performed so well that other systems were constructed to replace all of the modelocked Ti-Sapphire lasers. The fiber-based drive lasers have been operating reliably for more than one year and accelerator downtime associated with laser maintenance has been drastically reduced to nearly zero. A green-light version has been constructed using a Yb-doped fiber amplifier from the same vendor. At the moment, output power from this system is lower because the first 1064nm "test" laser we purchased produces relatively long optical pulses, ~ 100ps. We expect other seed lasers can be obtained that provide shorter pulses and higher overall output power. It seems likely this technology can be scaled to considerably higher power suitable for ERL applications [3].

LIFETIME MEASUREMENTS

Photocathode lifetime of modern DC high voltage GaAs photoguns is limited primarily by ion back-bombardment, the mechanism where residual gas at the cathode/anode gap is ionized by the extracted electron beam and back-accelerated toward the photocathode. A very simple model (Figure 3) suggests the possibility of improving photogun lifetime by simply increasing the size of the drive laser beam at the photocathode. For a large laser spot, total ion production at the cathode/anode gap

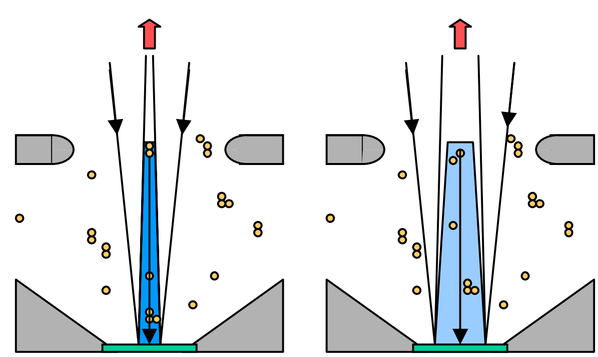

Figure 3: Two drive lasers conditions: small and large laser spots. Lifetime improves when the drive laser spot is increased, to distribute ion damage over a larger area.

remains the same, but ion damage would be distributed over a larger area and therefore QE at specific photocathode locations degrades more slowly. Lifetime enhancement, per this simple model, would be equal to the ratio of the two laser beam areas.

A new 100kV DC high voltage load-locked gun was used to test this idea [4]. Measurements were made at a dedicated gun test stand using bulk GaAs and green light at DC beam currents between 1 and 10 mA, and laser spot sizes of 320μm and 1550μm (FWHM). Indeed, lifetime was observed to increase using a larger laser spot (Figure 4), however not by the ratio of the two laser beam areas. Lifetime scaled by a factor of ~ 5 whereas the simple model predicted an enhancement of 18. This is not too surprising, considering that ion damage is not uniformly distributed across the photocathode surface: ions will be focused toward the electrostatic center of the photocathode. Furthermore, the ionization cross section differs for each residual gas species and this cross section varies with electron beam energy, from 0V at the photocathode surface to 100kV at the anode. In addition, the stopping depth of each ion within the material varies as a function of gas species and energy. Still, this measurement demonstrates remarkably high charge lifetime (> 1000 C) at average beam currents above 1 mA, and marks an important step toward appreciating the complicated factors that limit photocathode lifetime. The biggest drawback of this simple technique to improve photogun lifetime is that strict ERL emittance specifications may preclude using a large drive laser spot.

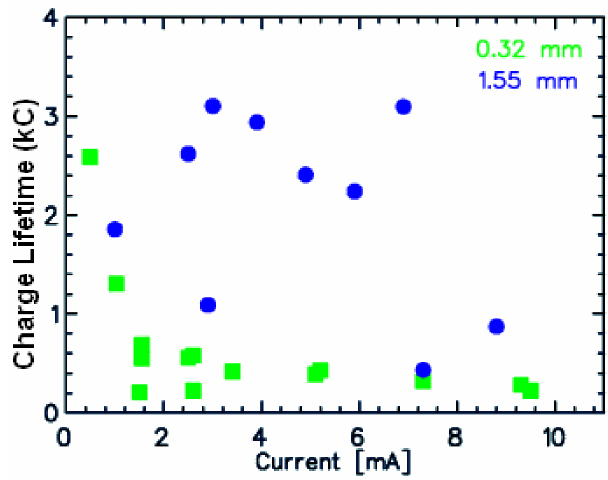

Figure 4. Charge lifetime measurements as a function of average beam current using different laser spot sizes. The highest charge lifetime was obtained using the larger laser spot.

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