OPTICAL ISOLATION TRANSFORMER FOR PULSED POWER APPLICATIONS*

Matthew Heino⁺

Bechtel Nevada 161 S. Vasco, Suite A, Livermore, CA 94550

Abstract

Described is a system that can provide electrical power to stacks of switching circuits while maintaining exceptional isolation between high voltage planes. High power laser diode bars are used to illuminate highly efficient photovoltaic cells. This is accomplished using efficient and cost-effective lens ducts and optical fiber segments. Such a system can be very efficient in transmitting optical power to the photocell. Using a glass lens duct we can achieve a theoretical isolation of 200 kV using a unit no bigger than a conventional dc-dc converter with isolation of only 50 kV. The trade off being total electrical efficiency, which is predicted to still be as high as 44%.

I. INTRODUCTION

In many high power systems, particularly those using power MOSFETs and IGBT's switch high currents and voltage. However, the gate driver circuitry have low power connections in close proximity to the high voltages. Power isolation transformers are used to isolate the circuit power supply from the switching potentials. In many cases this is an effective and relatively inexpensive means for isolation. There are cases where a superior isolation technique would enable power systems to new performance levels through compact construction, however, the expense of this system is such that it would be used only in cases where the extreme isolation is critical. Most isolators of the 5 watt size provide about 50kV of isolation. An optical power isolator has the potential of providing 200kV of isolation in a package with a similar footprint as a typical isolator.

There is a growing market for high average power laser diode bars and their cost has become quite reasonable. Just a few years ago this type of photonic power system would have been prohibitively expensive. The laser wavelength matches the peak responsivity of silicon photocells and so the efficiency of these cells when illuminated by this source achieves better than 66% efficiency. A glass lens duct provides the high isolation and so the power connection is light itself. The high efficiency of the photocell, laser bar, and the lens duct means that the total electrical conversion is about 44% less the cooling.

II. EXPERIMENTAL SETUP

This apparatus is comprised of 3 basic parts, light source, light transport, and photocell as follows.

A. Laser source.

We purchased an un-mounted 20 W cw GaAlAs laser bars with resonator length of 1,000 μm array length of 1 cm and height of 140 μm and emit at 808nm. This efficiently converts electric current into photonic power. The bar is packaged by soldering the p-side to a 2mm thick copper submount using In/Ag/Pb solder. This served as the anode contact, and as a heatsink. The cathode was a copper foil soldered to the n-side of the laser diode, as shown in figure 1.

Figure 1. Laser emission propagates to the right. The anode/heatsink is 2mm thick and acts to spread the heat load for the TEC.

The laser does generate a lot of waste heat, which must be removed. Plus the lower the temperature the bar can be maintained at, the more efficient it will operate, as high as 70%. We deposited a gold silkscreen onto the ceramic base of a thermal electric cooler (TEC) to which we soldered the copper submount and the positive terminal of the power supply. The hot side of the TEC was then air cooled. At full laser current the TEC could maintain the laser at -20 degrees F, but at that level there is a trade off between the gain in laser efficiency and the power demands of the TEC.

* This work was supported by Department of energy contract # DE-AC-08-96NV11718 and was performed at The Lawrence Livermore National Laboratory in Livermore, CA.

⁺heino1@llnl.gov

B. Light Transport and electrical isolation

Lens ducts have been used effectively to funnel diode laser light in many applications [5]. Most examples of this type of optic, however, are precise optical elements of pristine quality [6], and so of very high cost. It has been

Figure 2. Silica glass slide, tapered and polished into an effective lensduct. This length of glass could theoretically isolate 600kV. In practice it is the housing that will limit your isolation

found that silica glass microscope slides [1], once shaped and polished, make an adequate quality lens duct at low cost. Silica glass also has a very high dielectric strength, about 300 volts per mil, which is what provides the electrical hold off.

Figure 2 shows such a lens duct. Laser light is first conditioned using a segment of optical fiber as a cylindrical lens. This collimates the highly divergent fast axis of the diode output. A lens duct is hybrid optical element. It is a lens in that some of the light is focused as in any other lens. It is also a duct, relying on total internal reflection to funnel the light to the output. This total internal reflection could be augmented by depositing a thin dielectric film on the edges of the lens duct to act like the clad layer in optical fiber. This would increase throughput as well as optically isolate the lens duct from the potting compound that this device would be housed in.

The duct output is then ball lens coupled to five 200/230 optical fiber segments [1,7]. This is done because the photocell can only handle 2W of optical power over its active area before internal resistance becomes significant.

C. Photocell

The photocell chips we used had an active area of $\sim 12 \text{ mm}^2$ on a square substrate of only 5 mm per side. The four gold electrodes evenly extract current from the cell through wirebonding to a main anode. The whole back surface is coated in gold for the cathode for easy and compact mounting. The photocell was positioned 3mm from the fiber exit aperture by an optical epoxy window. Each cell produces a maximum of 1 volt, and photo generated current depends of the incident optical

intensity. The five cells are then connected in series to produce 5 volts. Efficient step up converters can then be used to produce the desired voltage for the application. The best possible performance for 10 watts of incident optical power means the photo cell will deliver 5.5 watts of electrical power.

Although this performance seems radical as compared to photocells most people are familiar with, it actually isn't [2,3]. This performance is due to our laser source, which is monochromatic and very intense.

III. CONCLUSIONS

As can be seen in figure 3 the fiber output projects a majority of light evenly onto the photocell.

The lack of a hard clad layer on the lens duct

Figure 3 a fiber output profile. At 3mm this spot is approximately 4mm across.

causes sensitivity to the environment around the duct. This incurs out coupling losses, which is to say that the light loses confinement. Antireflection coatings on all apertures would also reduce loss of light.

Alignment of laser to lens duct is quite critical. The ceramic plate on the cold side of the TEC could be customized to provide a structure that will auto align laser and lens duct, simplifying the manufacturing process. However such machining was not available to me and alignment was accomplished by hand in a 'best guess' manner.

To enhance laser lifetime, drive current was kept to 10 amps. Operating in this manner the laser should last indefinitely.

Figure 4 shows the performance of a single cell under various load and illumination levels. The expected load for this system will be a storage capacitor bank, which is the actual supply for the application. The laser, although operating continuous wave, need only be on for a short time to charge the capacitors. This long pulsing of the

laser reduces the idle power consumption, increases laser lifetime and reduced the demand on the laser cooling.

Cost of this system could be as low as \$25 per watt

Figure 4. The IV curve for a photocell under various illumination levels. Illuminating the cell with anything higher than 5 watts is ineffective, and will damage the cell.

Even as a single unit, cost would be reasonable for this level of isolation and specialization.

IV. REFERENCES

- [1] M. Heino, "Photonic power delivery through optical fiber using very high power laser diode arrays", SPIE proceedings Vol.3613, Jan.1999. DOE/NV/11768--281
- [2] G. Landis, "Solar cells for laser power receivers", Tech.Digest 7th International Photovoltaic science & engineering conf.,Nov 1993.
- [3] G. Landis, "Photovoltaic receivers for laser beamed power", J.Propulsion & Power,Vol9, No.1,pp105-112, 1993.
- [4] M. Emanuel, "High power laser diodes at various wavelengths", SPIE vol.3001 pp2-6, Feb.1997.
- [5] R. Fu, "Design of efficient lens ducts", App.Optics, Vol.1 no.18, p4000-4003, June 1998.
- [6] R. Beach, "Applications of microlens-conditioned laser diode arrays", SPIE Vol.2383, pp283-297, Feb 1997.
- [7] R. Wilson, "Ball-lens coupling efficiency for laser diode to singlemode fiber", App.Optics Vol.37, No.15, pp3201, May 1998.