Revista Brasileira de Aplicações de Vácuo, v. 27, n. 1, 11-14, 2008.

FIBER OPTIC LASER BEAMS COMBINER FOR THREE DIFFERENT WAVELENGTHS

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Received: November 1st, 2007; Revised: February 20, 2008

Keywords: Laser, Laser Beam Combiner, Fiber Optic.

ABSTRACT

In this work we describe a simple fiber optic laser beams combiner prototype for three different wavelengths. The qualitative results described here concern only two of the input branches of the combiner, i.e., only the combination of two beams will be analyzed. The preliminary results obtained are discussed and compared with those obtained from a conventional lumped beam combiner that uses seven mirrors and four beam splitters. These show the feasibility of using the present device to combine laser beams with different wavelengths. Furthermore, the results are better than those obtained with the conventional beams combiner, so far as stability and transmission coefficients are concerned.

1. INTRODUCTION

Since the 80´s decade Brazil has been investing in research and development of techniques to obtain enriched uranium, to be used as nuclear fuel. These works have been focused chiefly on the Atomic Vapor Laser Isotope Separation (AVLIS) and the centrifugation techniques. The research on AVLIS is being performed in the Photonics Division of the Advanced Studies Institute (IEAv/EFO) [1-3]. The physical principle of the laser methods for uranium isotope separation is the differentiated capacities possessed by the different isotopes of absorbing light of particular frequencies. The isotopic differences in the absorption spectra are caused by the volume effect of the nucleus and by the nuclear spin of the isotopes. The electronic energy levels present shifts in the visible range of the spectrum, and such shifts allow one of the isotopes to be selectively excited by a monochromatic laser beam. Thus, if a mixture of two isotopes is irradiated by a laser, at a resonant frequency and with an enough narrow linewidth, the light of the laser may be preferentially absorbed by one of the isotopes.

AVLIS is based on this fact. First, the material that is formed by an isotopic mixture is vaporized by an electron beam gun or by other techniques, such as laser ablation or cathode sputtering. The desired isotope, present in this vapor, is selectively excited by a laser beam that passes through it. In order to be ionized, at the visible spectrum range, the atoms must absorb at least three different photons so that the total energy of these photons together is greater than the first ionization limit, 6.18 eV for uranium. These three-photons are supplied by three dye laser systems pumped by copper vapor lasers in a MOPA configuration. These three-photons are combined into one single laser beam that interacts with the atoms to lead them to photoionization. After the photoionization, the ions can be deflected by electric and/or magnetic fields and guided up to a collector located in a place not accessible to the neutral 238U isotope. AVLIS more detailed description can be found in the literature [1, 2].

In this work we describe a simple fiber optic laser beams combiner prototype for three different wavelengths. The qualitative results described in this work concern experiments on just two branches of the beam combiner i.e., only the combination of two beams will be analyzed. The preliminary results are discussed and compared with those obtained from a conventional beam combiner using seven mirrors and four beam splitters. These show that is possible to use fiber optic device to combine laser beams with different wavelengths. Furthermore, the results are better than those obtained with the conventional beams combiner, so far as stability and transmission coefficients are concerned.

2. RESULTS AND DISCUSSIONS

In earlier experiments, we have used seven mirrors and four 50 % beam splitters to combine three different lasers beams as one can see in Figure 1. This setup resulted in four beams, having each one 23,3 % of the total input laser beams intensity, considering 99 % mirrors reflectivities and 50 % beam splitter transmission, without any other losses. However, this setup is very hard to be aligned and it needs an automatic feedback system to remain aligned for long periods.

Therefore, in order to avoid this misalignment and reduce the time required to align the setup, we are studying and designing a prototype of a new laser beams combiner for three different wavelengths, based on fiber optics. Figure 2 shows the experimental setup diagram of this prototype. Three 3M FG 200 UAT optical fibers, each with 1 m length, were assembled in four SMA 905 connectors, each fiber entrance assembled to a SMA 905 connector, and the three

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fibers exit assembled at the same SMA 905 connector, which we called SMA C (see Figure 3 (b)). This exit SMA C connector is attached to an ADASMA connector, that is also connected to the 3M FG 1.0 UAT fiber entrance (see Table 1). So, this prototype was made from a SMA 905 connector assembled with three fibers exit that is, by its turn, connected at an ADASMA connector, that is also connected to the entrance of another fiber. Hence, the different laser beams exiting from the 3M FG 200 UAT fibers are launched directly at the same 3M FG 1.0 UAT. Two different lasers were used to obtain the preliminary results and test our combiner. An helium neon and a Nd:YAG lasers were used to launch two different laser wavelengths into just two branches of our setup, to be combined into one single beam. Figure 3 (a) shows the SMA 905 and ADASMA connector details, while Figure 3 (b) shows the top vision of the three fibers assembled to the same SMA 905 connector (SMA C). One can observe that the assembled fibers are not parallel, neither centered at SMA connector. Although not yet properly assembled, this first prototype was used to test the concept.

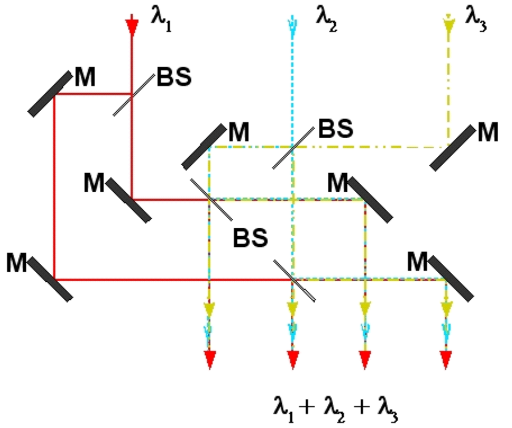


Figure 1 - First experimental setup used. M = mirrors and BS = Beam Splitter.

Table 1 - Diameter and numerical aperture for 3M optical fibers specification.

	3M FG-200-UAT	3M FG-1.0-UAT
Core Diameter	200 ± 5 μm	1000 ± 25 μm
Cladding Diameter	250 ± 5 μm	1250 ± 25 μm
Numerical Aperture	0.16 ± 0.02	0.16 ± 0.02

Figure 4 shows the qualitative experimental results. Figures 4 (a) and (b) show, respectively, the HeNe laser output when Nd:YAG laser is off and Nd:YAG laser output when HeNe laser is off, at the exit of the SMA C connector. Figure 4 (c), on the other hand, shows both laser outputs at this same SMA C connector, when both lasers are on. One can see from this figure that both laser beams are not completely combined at the screen. Finally, Figure 4 (d) shows both laser outputs at 3M FG 1.0 UAT fiber exit when the exit of SMA C connector is launched directly into the 3M FG 1.0 UAT fiber entrance, using an ADASMA connector. As result one can observe that both laser beams are completely combined at the screen. Figure 4 (d) also shows that the two beams have different diameters, but they are centered on the fiber axes. The apparent difference in diameter is due to the fact that the intensity of the Nd:YAG beam is 10 times greater than the intensity of the HeNe beam.

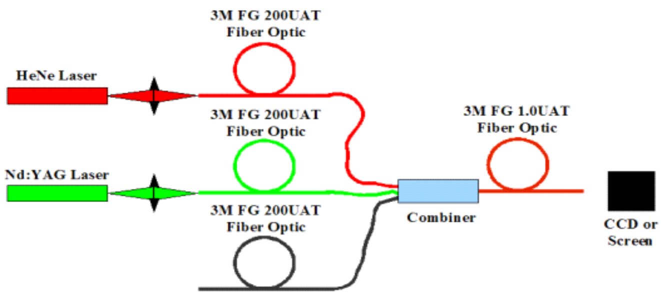
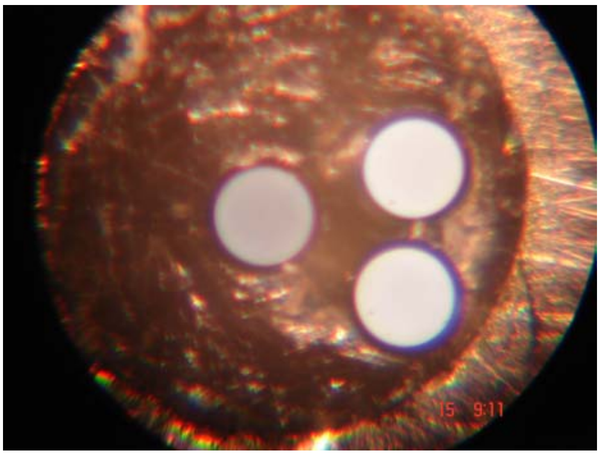


Figure 2 - Experimental setup used in this work.

(a)



(b)

Figure 3 - (a) SMA 905 and ADASMA connector; (b) top vision of three fibers exit assembled at same SMA 905 connector (SMA C).

(a)

(b)

(c)

(d)

Figure 4 - Qualitative experimental results obtained from our first combiner prototype. (a) HeNe laser output from SMA C exit when Nd:YAG laser is off; (b) Nd:YAG laser output from SMA C exit when HeNe laser is off; (c) both laser output from SMA exit; (d) both laser outputs at 3M FG 1.0 UAT fiber exit.

The fiber optic power transmission can be estimated using a simple theoretical model to calculate the fraction of transmitted by incident power of a Gaussian Beam sent through a circular aperture [4], whose diameter is the same of the core fiber, multiplied by fiber optic transmission coefficient per meter and by the reflectance coefficient for normal incidence of the beam at each fiber extremity [5]. Hence, one can estimate the fiber optical laser beam combiner transmission coefficient, η(w), using:

$$\eta(w)=\left[1-\exp\left(-\frac{2a^2}{w^2}\right)\right]\times\left(\gamma^L\right)\times\left[1-\left(\frac{n-1}{n+1}\right)^2\right]^N \qquad (1)$$

where $2a$ is the core fiber optic diameter, w is the radius of the spot size impinging the core fiber optic, γ is the fiber optic transmission coefficient for one meter, L is numerically equal to fiber optic length, n is the core fiber refractive index and N is the number of interface air/glass of normal beam incidences.

Figure 5 shows the fiber optical laser beam combiner transmission coefficient estimation as a function of spot size, w, of a Gaussian beam impinging normally: (a) through an aperture of diameter $2a$ = 200 μm radius, L = 0 and N = 0; (b) through a $2a$ = 200 μm core diameter fiber optic L = 4 m long, γ = 0.98 per meter, n = 1.457 and N = 2; (c) through a $2a$ = 200 μm core diameter fiber optic L = 1 m long, γ = 0.98 per meter, n = 1.457 and N = 2, coupled to a $2a$ = 1.0 mm core diameter fiber optic L = 3 m long, γ = 0.98 per meter, n = 1.457 and N = 2. All curves show that the coupling loss is very small only in the cases where the Gaussian beam spot size, δ, is lower than 60% of the core fiber radius.

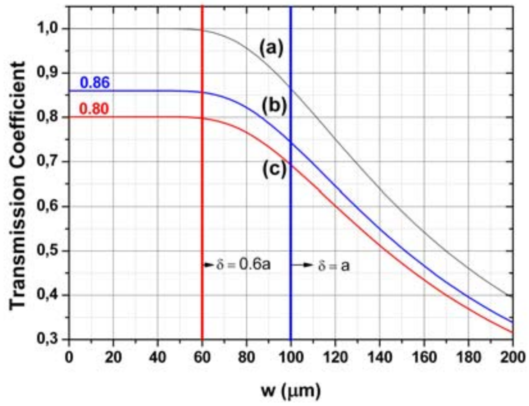


Figura 5 - Power transmission as a function of spot size, w, of a Gaussian beam incident: (a) through an aperture of a = 100 μm radius; (b) through a 2a = 200 μm core diameter fiber optic 4 m long; (c) through a 2a = 200 μm core diameter fiber optic 1 m long coupled to a 1.0 mm core diameter fiber optic 3 m long.

In spite of the good spatial combination between the two beams, only approximately 70% energy coupling efficiency was obtained, for the complete fiber combiner system after optics alignment optimization. This result shows that improvements need to be made to reduce the spot size launched by the optical system. Nowadays, we are working towards improving the optical system used to launch the beams at the fibers, and the to assembling the three fibers exit at same SMA connector to obtain a better centering and parallelism, to have each fiber cladding touching the other. We are also planning to test other configurations of this combiner. For instance, improvement can be expected, with transmission coefficient of 0.86, at least, as theoretically previewed, by welding all fibers connections. In our earlier experiments setup, where we used seven mirrors and four beam splitters to combine three different lasers we obtained four beams having each 23,3 % of each laser beam intensity. That setup needs an additional optical system to overlap the four resultant beams to delivery a total transmission coefficient of 0.932. Note that this value is obtained only when new mirrors and beam splitters are used. When the time of use increases the transmission coefficient decreases, arriving levels of 0.5 for the total transmission coefficient, due to dust at the optical surfaces and further coating thin films degradations. This fact implies in changing the mirrors and beam splitters and new tedious realingments are required.

3. CONCLUSIONS

A fiber optical laser beams combiner prototype for three different wavelengths was built. This prototype was made from a SMA 905 connector assembled with three fibers exit that is, by its turn, connected at an ADASMA connector, that is also connected to the entrance of another fiber. Hence, the different laser beams exiting from the 3M FG 200 UAT fibers are launched directly into the same 3M FG 1.0 UAT. As result one can observe that all laser beams are completely combined at 3M FG 1.0 UAT fiber exit. In spite of a good combination, just a poor intensity coupling was obtained, less than 70% for the complete fiber system. Improvements need to be made in the launching optical system and in the assembling of the three fibers at the SMA C. However, the results obtained show that is possible to use this device to combine laser beams with different wavelengths. Furthermore, they are better than those obtained using a conventional beams combiner, that uses mirrors and beam splitters, so far as as stability and transmission coefficients are concerned.

ACKNOWLEDGEMENTS

The authors thank CNPq for grants: DT Proc Number 303433/2006-0 and PIBIC Proc. Number 110828/2006-2.

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