Delivery of F2-excimer laser light by aluminum hollow fibers

著者	Matsuura Yuji, Yamamoto Takashi, Miyagi Mitsunobu
journal or publication title	Optics Express
volume	6
number	13
page range	257-261
year	2000
URL	http://hdl.handle.net/10097/52113

doi: 10.1364/OE.6.000257

Delivery of F_2-excimer laser light by aluminum hollow fibers

Yuji Matsuura, Takashi Yamamoto and Mitsunobu Miyagi
Department of Electrical Communications, Tohoku University
Sendai 980-8579, Japan
yuji@ecei.tohoku.ac.jp

Abstract: A hollow fiber composed of a glass-tube substrate and an aluminum thin film coated upon the inside of the tube delivers F_2-excimer laser light. A smooth, aluminum thin film was deposited by using metal-organic chemical vapor deposition using dimethylethylamine:alane (DMEAA) as the precursor. It was shown that the transmission loss of the fiber with a 1.0-mm inner diameter was as low as 0.5 dB/m for the fiber with 1.0-mm diameter when the bore of the fiber is pressurized with an inert gas to remove the absorption of air. When the fiber is bent at the radius of 30 cm, the additional loss was 1.6 dB.

OCIS codes: (060.2310) Fiber Optics; (140.2180) Excimer lasers

---

References and links

1. H.G. Craighead, J. C. White, R. E. Howard, L. D. Jackel, R. E. Behringer, J. E. Sweeney and R. W. Epworth, “Contact lithography at 157 nm with an F_2 excimer laser,” J. Vac. Sci. & Technol. B **1**, 1186-1189 (1983).
2. U. Stamm, I. Bragin, S. Govorkov, J. Kleinschmidt, R. Patzel, E. Slobodtchikov, K. Vogler, F. Voss and D. Basting,” Excimer laser for 157 nm lithography,” in *Emerging Lithographic Technologies III,* Yuli Vladimirsky, ed., Proc. SPIE **3676**, 816-826 (1999).
3. H. Nagai, “Applications of excimer lasers,” Rev. Laser Eng. **23**, 1038-1050 (1995).
4. P. R. Herman, K. Beckley, B. Jackson, K. Kurosawa, D. Moore, T. Yamanishi, and J. Yang, “Processing applications with the 157-nm fluorine excimer laser,” in *Excimer Lasers, Optics, and Applications,* H Shields and P E Dyer, eds., Proc. SPIE **2992**, 86-95 (1997).
5. H. Hosono, M. Mizuguchi, L. Skuja, and T. Ogawa, “Fluorine-doped SiO_2 glasses for F_2 excimer laser optics: fluorine content and color-center formation,” Opt. Lett. **24**, 1549-1551 (1999).
6. V. Liberman, M. Rothschild, J. H. C. Sedlacak, R. S. Uttaro, A. Grenville, A. K. Bates and C. Van Peski, “Excimer-laser-induced degradation of fused silica and calcium fluoride for 193-nm lithographic applications,” Opt. Lett. **24**, 58-60 (1999).
7. R. S. Taylor, K. E. Leopold, R. K. Brimacombe and S. Mihailov, “Dependence of the damage and transmission properties of fused silica fibers on the excimer laser wavelength,” Appl. Opt. **27**, 3124-3134 (1988).
8. Y. Matsuura and M. Miyagi, “Flexible hollow waveguides for delivery of excimer-laser light ,” Opt. Lett. **23**, 1226-1228 (1998).
9. Y. Matsuura and M. Miyagi, “Aluminum-coated hollow glass fibers for ArF-excimer laser light fabricated by metallorganic chemical-vapor deposition,” Appl. Opt. **38**, 2458-2462 (1999).
10. T. Kodas and M. Hampden-Smith, Ed., *The Chemistry of Metal* CVD (VCH, Weinheim, 1994).
11. M. G. Simmonds, E. C. Phillips, J.-W. Hwang, and W. L. Gladfelter, “A stable, liquid precursor for aluminum,” Chemtronics **5**, 155-158 (1991).

---

1. Introduction

F_2-excimer lasers which oscillate at the wavelength of 157 nm are attractive and promising as a light source for lithography, material processing, and medical applications [1-4]. Some optical systems for industrial and medical applications which utilize the F_2-lasers have been already developed, however, these system have difficulty in the beam delivery system because a reliable and efficient optical fiber for vacuum-ultraviolet lasers does not exist due to

#22961 - $15.00 US Received March 14, 2000; Revised June 07, 2000

absorption and degradation in common glass and crystalline materials [5-7]. In the F_2 laser system, therefore, the laser beam is delivered to targets by using mirrors. This makes the system heavy and rigid because all the laser beam paths have to be in vacuum or inert gas atmosphere by employing a vacuum or high-pressure gas fitting and tubing.

We have developed a flexible hollow fiber composed of a silica glass capillary tubing with a thin aluminum film on the inside of the tube [8, 9]. The fiber shows low loss properties for ArF-excimer laser light (λ=193 nm) when flow of inert gas such as nitrogen and helium is introduced into the hollow core to remove absorptive ozone which is transformed from oxygen with radiation of high-energy density, ultraviolet light. We propose, in this letter, flexible and efficient delivery system for F_2-excimer laser light using the hollow fiber as the delivery medium. For delivery of F_2-excimer laser light, as described later, the bore of the fiber is pressurized with nitrogen to remove the absorption of air entirely.

2. Fabrication

As the substrate of the hollow fiber which we have developed, silica glass tubing with an inner diameter of 1 mm and 0.7 mm are used. Since the wall thickness of the glass tube is less than 75 μm, the tubing is highly flexible and bent into a radius smaller than 10 cm. An aluminum thin film is deposited on the inside of glass tubing by employing a metal-organic chemical vapor deposition (MOCVD) method [8, 10] by heating the tube with a small electrical furnace while vapor of dimethylethyamine:alane (DMEAA) [11] was injected into the bore of the glass tubing. Since aluminum deposition takes place only a part of the glass tube heated with the furnace, an aluminum thin film with a uniform thickness is deposited on the whole length of glass tubing (1-2 m) by slowly shifting the heater along the tubing.

The transmission properties of hollow fibers for F_2-excimer laser light are more affected by roughness of fibers' inner surface than ArF laser because of the shorter wavelength. Thus, we optimized the fabrication process of the aluminum-coated hollow fiber to reduce the surface roughness of aluminum film coated upon the inside of the fiber. One of optimized conditions is deposition temperature of aluminum. Since we found that a smoother film is formed under low temperatures, we changed the deposition temperature from 120 ºC to 80 ºC which is the lowest temperature where deposition takes place. Also we set the shifting speed of the small heater lower to obtain a enough thickness of aluminum for effective guiding of laser light in the hollow core. Another factor which affects the surface smoothness is vapor pressure of DMEAA. Although, in the deposition process, the bore of glass tubing is kept in vacuum by a rotary pump, high vacuum condition is not obtained for small-bore tubing with a small conductance for the vapor. This results in deposition of rough surface with clustered grains. To increase the conductance, we bundled 3 tubes for the 1.0 mm-bore fiber and 7 tubes for the 0.7 mm and deposited aluminum film simultaneously.

From observation with atomic force microscopy, we found that the inner surface roughness of the hollow fibers were reduced from 15 nm to 10 nm in root-mean-square value by optimizing the deposition conditions of aluminum.

3. Measurement

Figure 1 shows loss spectra of the aluminum-coated hollow fibers fabricated before and after optimizing the fabrication process. The spectra were measured by a conventional vacuum-ultraviolet monochromator with a deuterium light source and photomultiplier, which provides a scanning band from 120 to 350 nm. In the measurement, whole light path including the fiber's hollow core was kept in high vacuum at a pressure of 10^{-3} Pa by using vacuum attachment and turbo molecular pump. The effect of reduction in inner surface roughness of the hollow fiber is seen in the spectra as the decrease in the losses at short wavelengths where the roughness highly affects the transmission loss.

In preliminary test using a F_2-excimer laser, we found that it is necessary for effective transmission to apply pressure into the bore of hollow fibers with inert gas. Therefore, we

Received March 14, 2000; Revised June 07, 2000

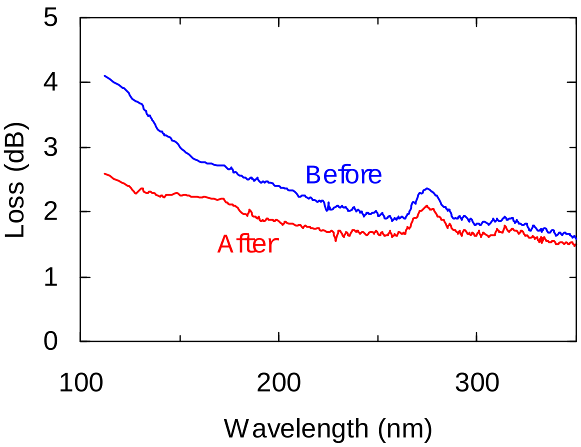


Fig. 1 Loss spectra of the aluminum-coated fibers fabricated before and after optimizing the fabrication process. The inner diameter of the fiber is 1.0 mm and the length is 1m. The fiber is excited by a Gaussian beam with a wide divergence angle of 3.7º at FWHM.

made a gas introducing attachment which is schematically shown in Fig. 2. The laser beam emitted from the laser window is focused to input end of a hollow fiber by a MgF_2 lens with a focal length of 180 mm. Since the unfocused beam with a low energy density has not to be pressurized, those parts are purged with nitrogen at a low pressure. On the beam path that is close to the fiber's input end and the hollow core of the fiber, the energy density of laser light is so high that a slight amount of air contained in the regular grade, purified nitrogen absorbs the laser light. To remove this effect, we introduced high-speed gas flow into the hollow fiber by pressurizing the input end of the hollow fiber. As shown in Fig. 2, the input end of hollow fiber is enclosed in a stainless steel vessel with a CaF_2 window to apply a high pressure. Owing to the bellows joint, the vessel can be moved independently to the lens and other optics for optical alignment.

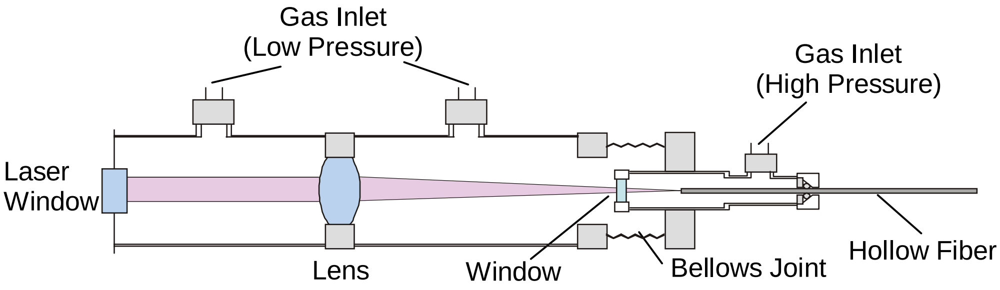


Fig. 2• Gas introducing attachment for hollow fibers

Using the gas introducing attachment, we firstly measurde the pressure dependence of the transmission losses of the aluminum-coated fiber with the inner diameter of 1.0 mm and the length of 1 m. The F_2-excimer laser equipment employed in the measurement emits the pulse energy of around 1 mJ at a repetition rate of 100 Hz. As seen in the result shown in Fig. 3, the losses decrease with the gas pressure and saturates at 0.5 dB for pressures higher than 200 kPa. Since gas breakdown at the focused spot was not observed at any gas pressure and we had same results with helium gas, this phenomenon may be due to slight air-leak in the attachment or an impurity contained in the gas. The pressure which is necessary for loss saturation may be lowered by using a higher purity gases. To keep whole light path in vacuum will be also effective although a vacuum attachment will be somewhat complicated.

Received March 14, 2000; Revised June 07, 2000

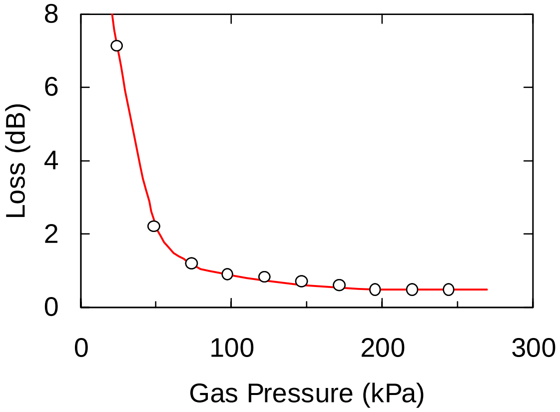


Fig. 3 Transmission losses of aluminum-coated hollow fiber versus purged nitrogen pressure. The inner diameter of the fiber is 1.0 mm and the length is 1m.

Figure 4 shows the bending losses of the aluminum-coated hollow fibers with the inner diameters of 0.7 mm and 1.0 mm when nitrogen gas with the pressure of 250 kPa was introduced. The straight losses are 0.5 dB for the 1-mm bore fiber and 1.0 dB for the 0.7 mm. Although the bending induces a loss increase, the losses at the bending radius of 0.3 m are allowably low as 2.1 dB and 3.1 dB for the 1.0 mm and 0.7 mm bore sizes, respectively. Although durability tests of the aluminum hollow fiber had not performed with F_2 laser light because of limitation in the laser equipment, we had tested the fiber with ArF laser light with pulse energy of 8 mJ and repetition rate of 100 Hz. After transmission of more than 10^6 pulses, no degradation was found and it is expected that similar results will be obtained with F_2 laser light. The inner aluminum film is chemically stable since no degradation was found in the transmission properties after the fiber was kept in air for 1 year. Also we confirmed mechanical stability of fiber and its inner coating by repeated bending tests.

We also measured beam profiles emitted from the hollow fibers and the results are shown in Fig. 5. The beam profiles were detected by using a thermal paper and measured gray-scale images were processed by a PC graphic software. Fig 5(a) is the beam shape of the laser

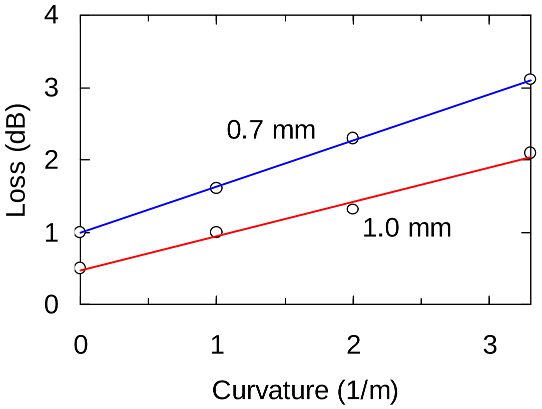
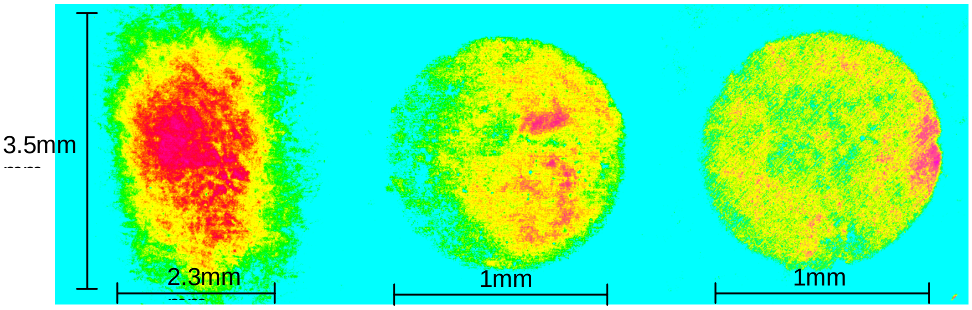


Fig. 4 Measured straight and bending losses of aluminum hollow waveguides for F_2 laser light (λ=157 nm). The length of the fibers is 1 m and the bore diameters are 1 mm and 0.7 mm.

#22961 - $15.00 US
Received March 14, 2000; Revised June 07, 2000

source which is rectangular. Fig. 5(b) and (c) are beam shape of output beam from a straight and a bent hollow fibers, respectively. The beam profiles were measured at the distance of 2 mm from the output end of hollow fibers with the inner diameter of 1 mm. We found that the rectangular beam shape of the laser source is converted to circular beam with an almost flat-top power distribution although some small peaks are seen in the both profiles.



(a) (b) (c)

Fig. 5 Power density profiles of (a) laser source beam, (b) output beam from a straight hollow fiber, and (c) output beam from a bent hollow fiber. The profiles are measured by using a thermal paper and burn patterns are processed by a computer software.

4. Conclusion

We showed for the first time, as far as we know, that a hollow fiber composed of a glass tube substrate and an aluminum thin film coated upon the inside of the tube delivers F_2-excimer laser light with a low transmission loss. It was shown that the fiber should be pressurized with an inert gas such as nitrogen to remove the absorption of air.

Received March 14, 2000; Revised June 07, 2000