OPTICAL TRANSMISSION THROUGH A POLARIZATION PRESERVING SINGLE MODE OPTICAL FIBER AT TWO Ar^+ LASER WAVELENGTHS

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Abstract

The transmission characteristics of two Ar^+ laser wavelengths through a twenty meter Panda type Polarization Preserving Single Mode Optical Fiber (PPSMOF) have been measured. The measurements were done with both single and multi longitudinal mode radiation. In the single longitudinal mode case, a degrading Stimulated Brillouin Scattering (SBS) is observed as a backward scattering loss. By choosing an optimum coupling system and manipulating the input polarization, the threshold of the SBS onset can be raised and the transmission efficiency can be increased.

I. Introduction

Compared with the transmission of an optical field through the free space, the transmission through the optical fiber has special advantages. Mainly, it does not only provide the isolation of the transmitted field from the outer environment, but it also transforms the straight optical path into a flexible path which can be easily directed toward any particular point of interest. Particularly, the Polarization Preserving Single Mode Optical Fiber(PPSMOF) is suitable for maintaining the state of light polarization from the input to the output end of the fiber, regardless of the form of the fiber. The preservation of polarization during transmission through a PPSMOF is required in some sensor and measurement systems, e.g. the laser Doppler velocimeter, gyroscope and hydrophone.

In the laser Doppler velocimetry application, channeling the optical field through the PPSMOF is required in the transmission side, where as the receiving side can use a multi mode optical fiber to image the observation volume. Some investigations on the transmission problem of PPSMOF for velocimeter purpose have been reported.[1-4] The reported laser radiations are of the He-Ne (632.8 nm) and Ar^+(488.0 and 514.5 nm) lasers. The power of the first case is usually only of the order of several tens of milliwatts, while the second one is reported to be used up to 2 W although reported measurements show only up to 1.5 W. The transmission measurements have been done for the single and multi longitudinal modes radiation. For the single mode radiation, the transmission characteristics always show a saturated output limited by some non-linear effects.

This present work studied the transmission characteristics of Panda type PPSMOF with a cut-off wavelength of 480.0 nm for both single and multi longitudinal modes, at 488.0 and 514.5 nm wavelength radiation. The non-linear effect was related to the backward Stimulated Brillouin Scattering (SBS). By choosing the optimum coupling between laser and fiber, and transforming the input polarization characteristics, the threshold input power for the SBS effect could be raised and an improved power transmission efficiency was achieved.

II. Theoretical Considerations

The problems related to the optical transmission through the PPSMOF can be divided into three main problems i.e. the optical coupling between the laser and the fiber, the preservation of the input polarization at the PPSMOF output, and the suppression of the degrading non-linear effect inside the fiber. They will be briefly outlined below.

A. Laser-Fiber Optical Coupling

In the multi mode fiber, the mode number N_m is given by the following expression:

$$N_m = 2V/\pi - 1, \tag{1}$$

where

$$V = a(2\pi/\lambda)n_1\surd(2\Delta). \tag{2}$$

Here, a is the fiber core radius; $\Delta=(n_1-n_2)/n_1$ is the relative difference between the refractive indices n_1 and n_2, of the core and cladding region respectively; λ is the incident wavelength and V is the normalized frequency and called the V number of the fiber. For example, when a=50 micrometers, $n_1=1.451$, $\Delta=0.01$ and $\lambda=514.5$ nm, N_m will be about 78. When a laser light is launched at the input end, a speckled pattern will be observed at the output end. When a spatial coherent beam is required, such a noncoherent field is not favored. The required conditions for an optical fiber which will be operated in single mode is that the V-number shall be less than 2.405 and the launched wavelength shall be longer than the cut-off wavelength of the fiber. When these conditions are met then the output beam will be free from interference between different modes. For PPSMOF with cut-off wavelength of 480 nm, the single mode requirement limits the dimension of the core to be about 3 micrometers. For the single mode optical fiber, the condition to obtain the maximum power transfer is achieved when the quotient of the waist radius of the incident beam and the core radius of the fiber has the following relation,[5)]

$$(w_o/a) = 0.65 + 1.619V^{-1.5} + 2.879V^{-6}, \tag{3}$$

where w_o is the beam waist radius of the incident laser beam.

The emitting beam from the laser usually has a beam width wider than the beam width required by the above condition. For this reason, a focusing system is required to achieve the optimum w_o/a ratio. Generally the cross section of the output beam of a laser is Gaussian and therefore the focused beam is also Gaussian. The location of the beam waist of the output beam is also needed because the input end of the optical fiber will be placed at this position. The position of the beam waist of the output beam is dependent on the position of the beam waist in front of the focusing lens and also on the focal length of the lens. In addition, the input beam waist must be located at the front focal plane, in order for the position of the output beam waist to be located at the back focal plane.[6] The relationship between their beam waist values is expressed as

$$w_o = (\lambda f)/(\pi w) \tag{4}$$

where w is the beam waist radius in front of the lens, and f is the focal length of the focusing lens. The selection of the lens which will give the maximum value of power transfer is determined by measuring the size of the laser beam waist radius and then applying relations (3) and (4).

B. Polarization Characteristic in the PPSMOF

The polarization state of the light incident on the fiber input end is required to be preserved at the output of the fiber. In the ordinary single mode fiber there is usually a small amount of intrinsic birefringence due to the asymmetry of the core. Other external factors like bending, vibration or movement will introduce external birefringence to the small intrinsic birefringence. The coupling between two orthogonal polarization modes will destroy the polarization preservation. To overcome this problem, a PPSMOF of high birefringence has been developed so that any additional external birefringence will be negligible compared with high intrinsic birefringence. As schematically shown in Figure 1, an ideal PPSMOF is designed to behave as a linear birefringent material, and a linear input polarization will be maintained at the output of the fiber if it aligned to one of the two principal axes of the fiber. When the polarization is not aligned, generally an elliptical polarization will be found at the output. The polarization characteristics of birefringent material can be easily understood using the graphical method of spherical or Planar Poincaré Chart.[7)]

Figure 2 shows the geometrical cross section of some PPSMOF structures. In the linear birefringent fiber, the propagation velocity constant is not the same for two perpendicular x-y directions. The birefringence ,B, is defined as the difference between the two propagation constants, $B = \beta_x - \beta_y$. The linear birefringent fiber is fabricated by introducing radially asymmetrical structure (however it is symmetric with respect to two perpendicular lines, which define the principal axes) e.g. by making pit/tunnel along the sides of the core, forming asymmetrical structure of core/cladding, and introducing dopant material in the cladding or core area to produce stress-induced birefringence.[8)]

Besides the linear birefringent PPSMOF, there are also some attempts to produce the circular birefringent one. In the circular birefringent PPSMOF, the propagation velocity constants for right and left circular polarization are not the same. The birefringence is similarly defined as $B_C = \beta_R - \beta_L$. This fiber is made from a fiber with a helical path, or from twisted fiber with core of different geometries.[9)]

The linear birefringent PPSMOF is commercially available, although for Ar^+ wavelengths there are only limited sources, e.g. Panda and Bow-tie types. Methods for alignment of the input polarization to the one of the principal axes have been reported.[10-12)] In the experiment, a half wave plate is inserted in front of the fiber input and an analyzer at the back of the fiber output, and both are adjusted until a maximum extinction is observed at the output, which means that the output polarization state is linear. The theoretical consideration of this approach has been reported.[13)] When the input polarization is aligned to the bisector of the principal axes, clear dark and bright patterns will be observed along the fiber. The distance between two consecutive patterns is called the beat length L_B,

$$L_B = 2\pi/(\beta_x - \beta_y), \tag{5}$$

which is a measure of the degree of birefringence.

C. Non-Linear Effect in the PPSMOF

The non-linear effects which are generated inside a fiber used as an optical transmission media have been reported to include Stimulated Brillouin Scattering(SBS) and Stimulated Raman Scattering(SRS) effects.[14-15] Compared with the Stimulated Raman Scattering, which is dominant in the forward direction, SBS is dominant in the backward direction and produced losses in the advance direction. It is worth noting that SBS, together with four wave mixing effect, is very important in generating the phase conjugate wave.

The Brillouin scattering is a phenomenon produced from the interaction between light and acoustical waves.[16] In the optical fiber, the Brillouin scattering may be generated by an intense optical beam. Here the acoustic wave is produced by the beam itself and the scattering process is termed stimulated Brillouin scattering. The backward stimulated Brillouin scattering will attenuate the forward optical power transmission, and thus reduce the efficiency of transmission. The Brillouin frequency shift can be expressed as

$$\Delta\nu = 2v_s n_1/\lambda, \tag{6}$$

By using equation (6), and using the velocity of sound for fused silica, v_s, to be 5.96×10^3 m/sec., the frequency shift is calculated to be 35.44 and 33.62 GHz at Ar^+ wavelengths 488.0 and 514.5 nm respectively.

III. Experimental Results and Discussion

Some experiments have been performed to investigate the transmission properties of the polarizing preserving single mode optical fiber, which include the problems of coupling the beam into the fiber, polarization properties and effect of stimulated Brillouin scattering in the backward direction. The schematic diagram of the experimental set-up is shown in figure 3. The laser is an Ar^+ laser with a maximum output power of 5W for all radiation. The polarization controller is a zero order wave plate or an optical isolator. The backward radiation is observed using spectrum analyzer after a reflection by a quartz plate. The fiber is a twenty meters Panda type fiber with cut off wavelength of 480 nm and is a linear birefringent type.

To prepare the surface ends of the fiber, a good cleave is sufficient without polishing. A clean fiber surface can be detected by launching the incident wave at the input end and observing the output pattern of the other end to have a cross section of Gaussian profile. The output end is inspected by the same reverse procedure.

An optical coupler system, composed of focusing system and mechanical micro-position manipulator, is used to couple the laser and the fiber input end. Using equations (3) and (4), to guide the selection of the microscope objective lenses, a lens with a magnification power of 20X and numerical aperture of 0.35 was chosen. To reduce the effect of optical surface reflection, an anti reflection coating is required.

The performance of the coupler system is also determined by the mechanical repeatability and precision of the micro-position manipulator. The fiber ends are supported by fiber connectors, and each tip is placed inside an annular sapphire disc to maintain its position during high power laser illumination. The power transmission is monitored by measuring the power at the input and output ends of the fiber coupler. The polarization preserving characteristic of PPSMOF is fulfilled when the linear input polarization is aligned to the one of the birefringent axes. The input polarization is adjusted using a zero-order half wave retarder plate.

The measurements were conducted with multi and single longitudinal input modes. In the multi mode case, no other frequency was observed by optical spectrum analyzer for input power levels up to 1500 and 1800 mW for λ equals to 488.0 and 514.5 nm respectively. However, in the single mode case, a new generated frequency was observed at an input power level of 290 and 350 mW for λ equals to 488.0 and 514.5 nm respectively.

In the single longitudinal mode, the spectrum generated by non-linear effect was observed. As shown in figure 4, the generated backward spectrum is dominant compared with the pump field, while at the forward direction it was negligible. Calculations showed that these frequencies are related to the Brillouin frequencies predicted by equation (6).

Figures 5a and 5b show the relationships between the threshold power of SBS and the polarization angle, θ of the input polarization field. This threshold power is the input power at which the spectrum analyzer begins to detect SBS spectrum in the backward direction. The angular separation between the minimum thresholds is 90° which is the separation between the principal axes. The result of the experiment suggested that SBS can be suppressed or delayed to appear at a higher threshold by launching a linear polarization whose direction is the bisector of the principal axes.

The result of the measurements of the input-output power relationships are shown in figures 6a and 6b for λ equals to 488.0 and 514.5 nm respectively. The experiments were conducted for both the single and multi longitudinal modes. The results are compared with the results previously published by Brown et al.[2] for the multi longitudinal mode, and to Kaufman and Fingerson[4] for the single longitudinal mode. The result has a better performance compared with the result of Brown et al. The measurements of input-output power relationship for the single longitudinal mode was obtained for three different polarizations, linear and aligned to the principal axis, circular, and circular by isolator which also prevented reflected light to the backward direction. The result shows that input circular polarization is better than linear one, while using an isolator will give the best transmission performance. The result is compared with the result by Kaufman and Fingerson[4] for 514.5 nm, since there is no available data for 488.0 nm, which shows a factor of two improvement.

IV. Conclusion

The measurements of optical transmission through twenty meters PPSMOF were conducted at 488.0 and 514.5 nm radiation with single and multi longitudinal modes. For the single longitudinal mode, the transmission performance is degraded by the backward SBS. By choosing an optimum optical coupler and launching the input radiation through an isolator, which means that the input polarization is circular and no back reflected light enters the laser, a factor of two improvement in transmission performance was achieved.

IV. References

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Caption of Figures

Figure 1. A linear polarized light at the input of a linear birefringent PPSMOF will generally be transmitted as an elliptical polarized light at the fiber output, only when the polarization plane is parallel to one of the fiber principal axes then it will be linearly transmitted.

Figure 2. Diagram of the geometry of single mode optical fiber.

Figure 3. Schematic diagram of the experimental arrangement.

Figure 4. Observed spectrums of backward SBS field(SBS) above the threshold value, and laser field(L) at:

a). λ=488.0 nm, and

b). λ=514.5 nm.

The unit scale marked by the arrow corresponds to ,1.0GHz, one tenth of the free spectral range. At λ=488.0nm the frequency shift is 35.4GHz, while it is 33.26GHz for λ=514.5nm.

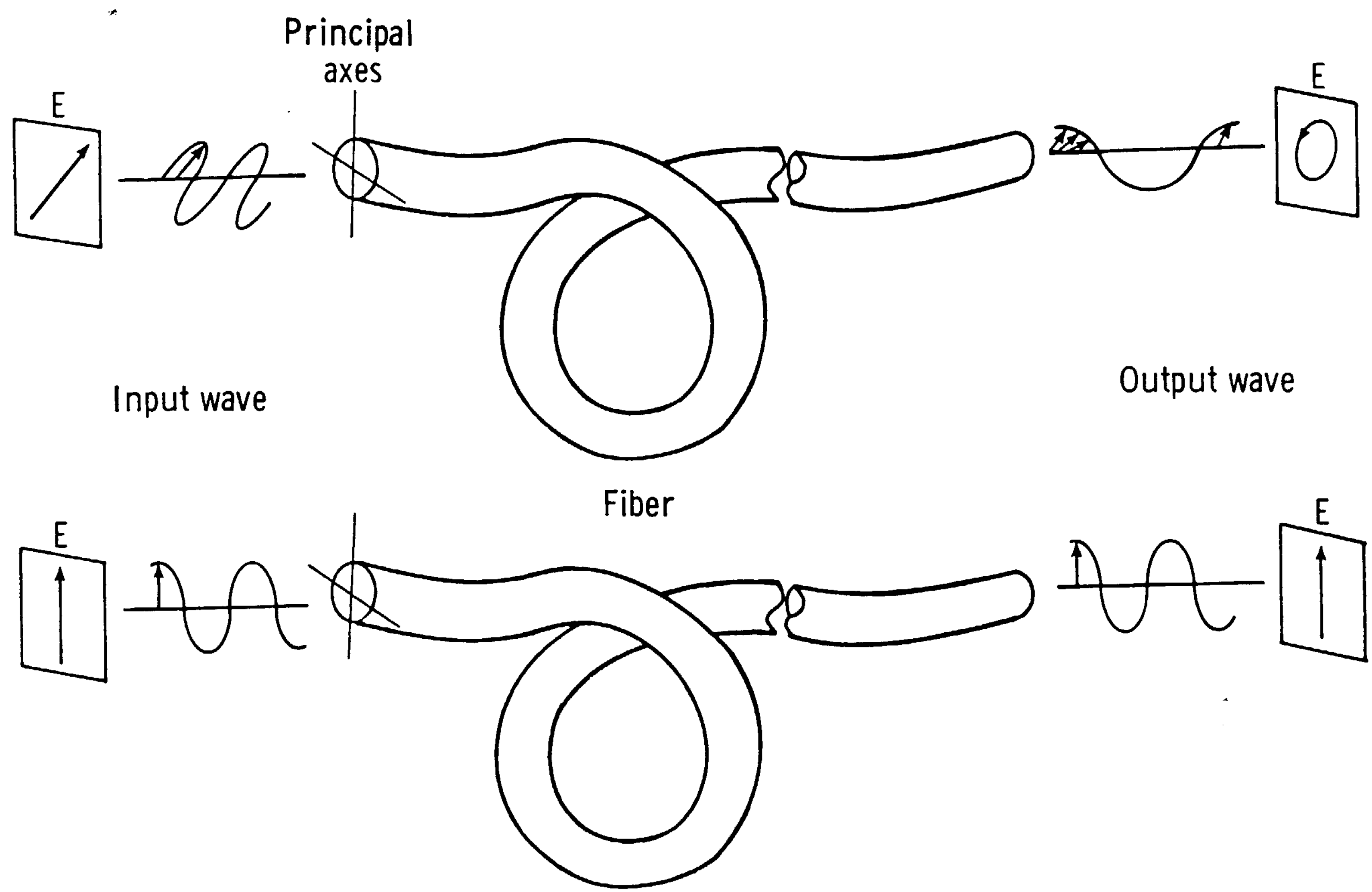
Figure 5. Experimental results of the relationship between the input threshold power of the backward Stimulated Brillouin Scattering and the angle of the input polarization θ at:

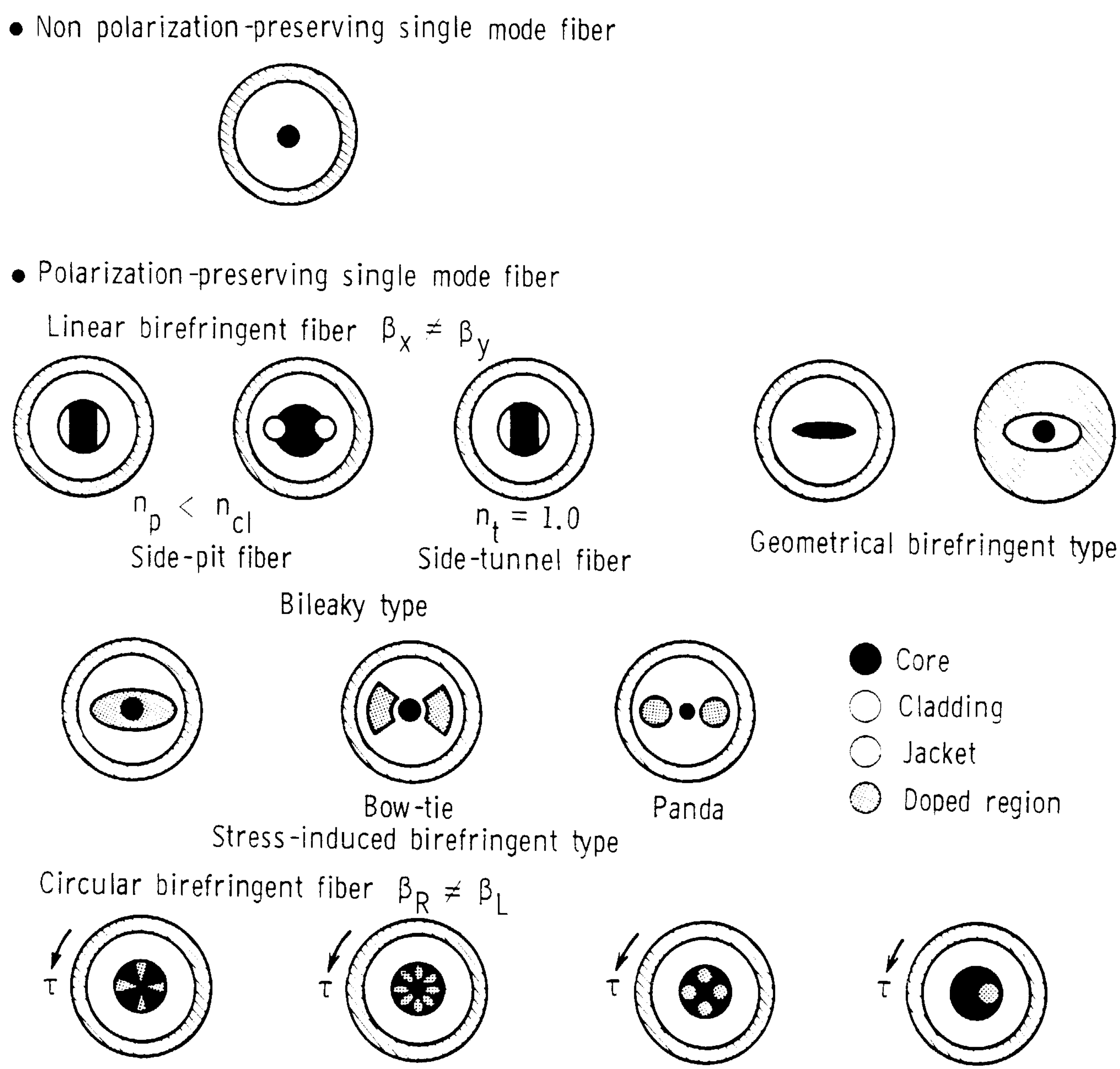
a). λ=488.0 nm, and

b). λ=514.5 nm.

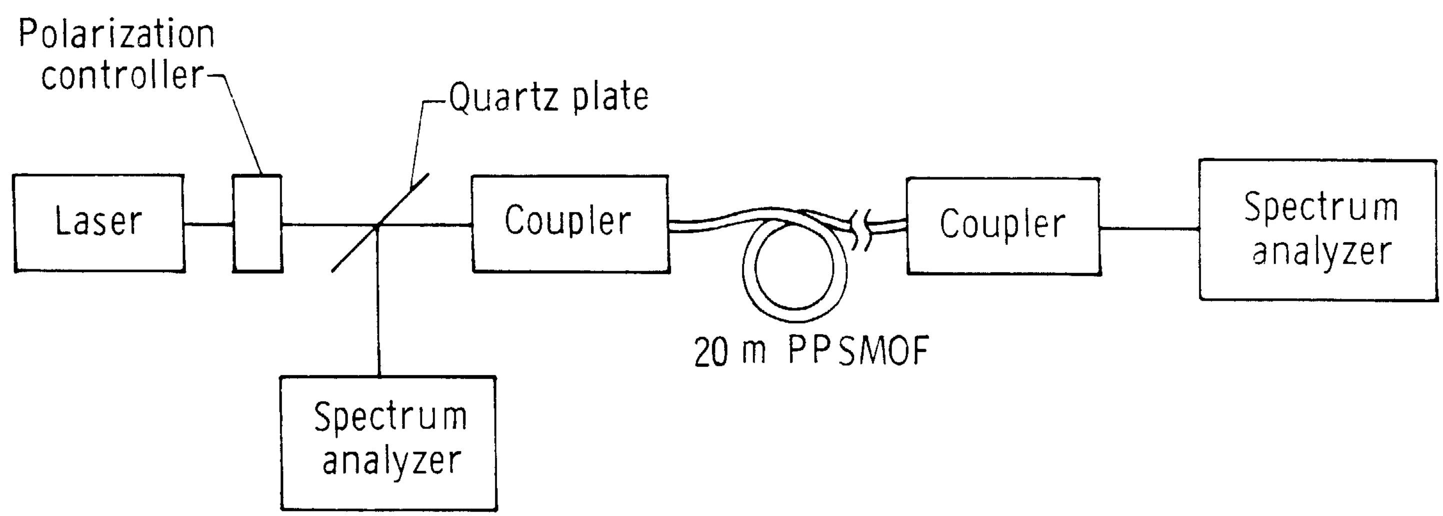
Figure 6. Experimental results of the power transmission measurements for twenty meters Panda type fiber:

a). at λ = 488.0 nm wavelength. The solid line indicates the data by Brown et al.[2] at multi longitudinal mode. b). at λ = 514.5 nm wavelength. The solid lines indicates the data by Brown et al.,[2] and Kaufman and Fingerson,[4] at multi and single mode radiation, respectively.

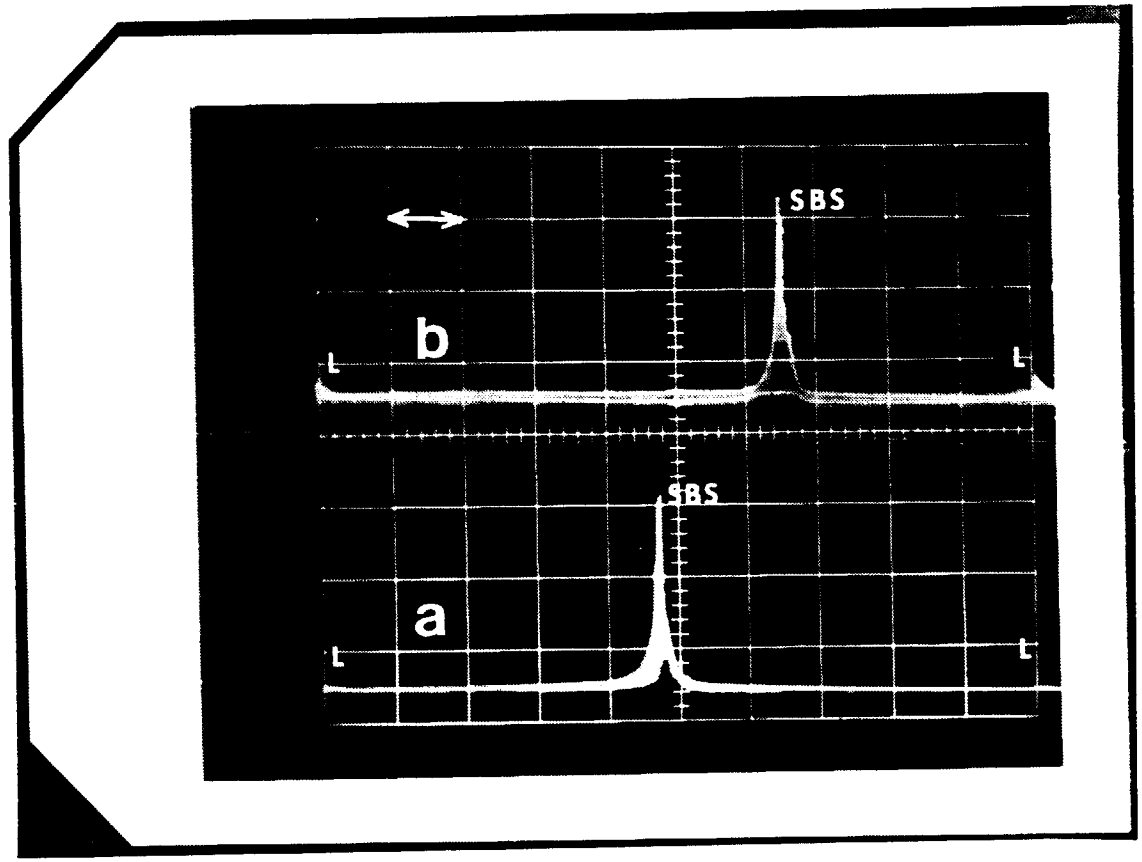

Principal
axes
E
E
Input wave
Output wave
Fiber
E
E

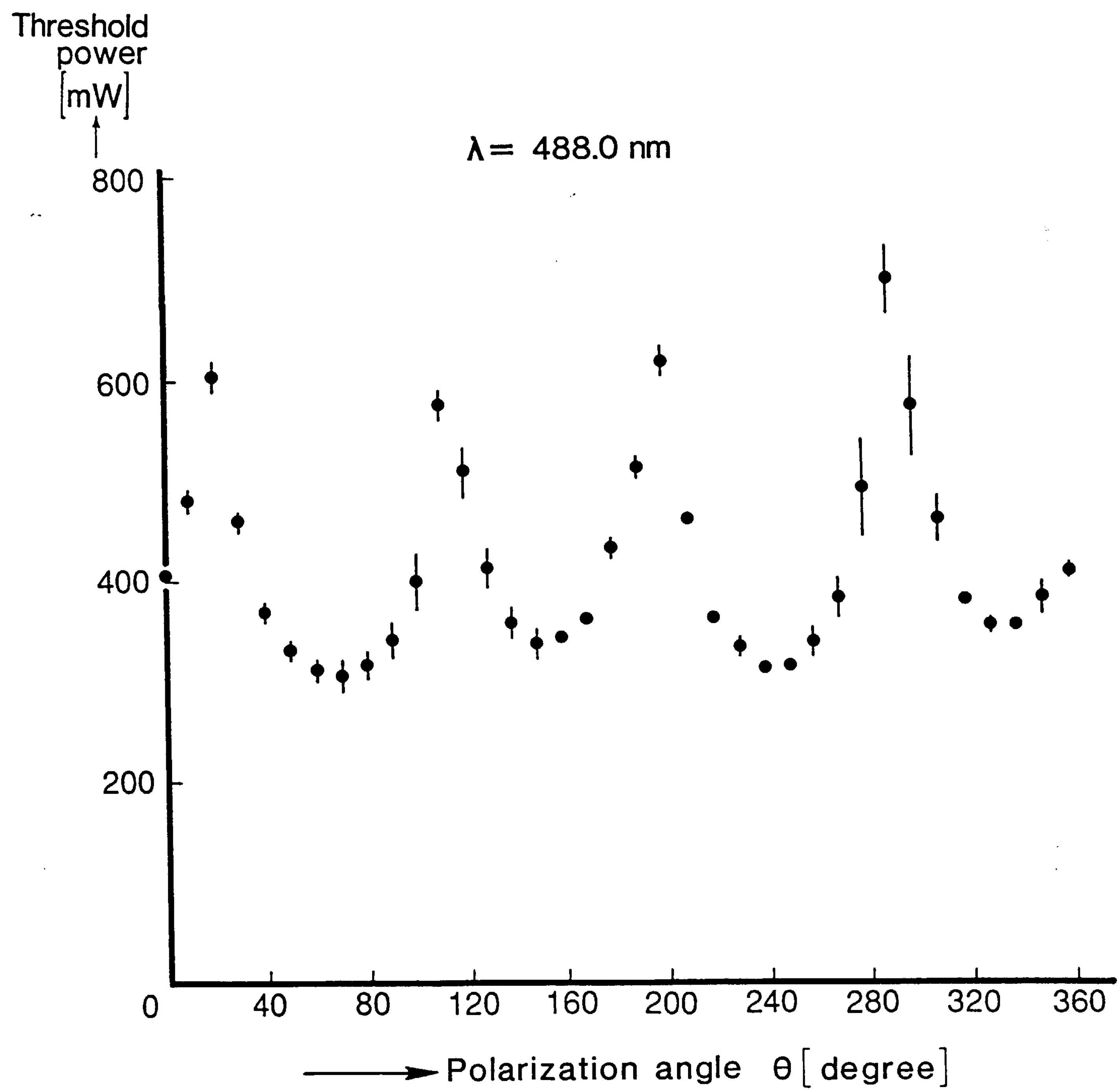


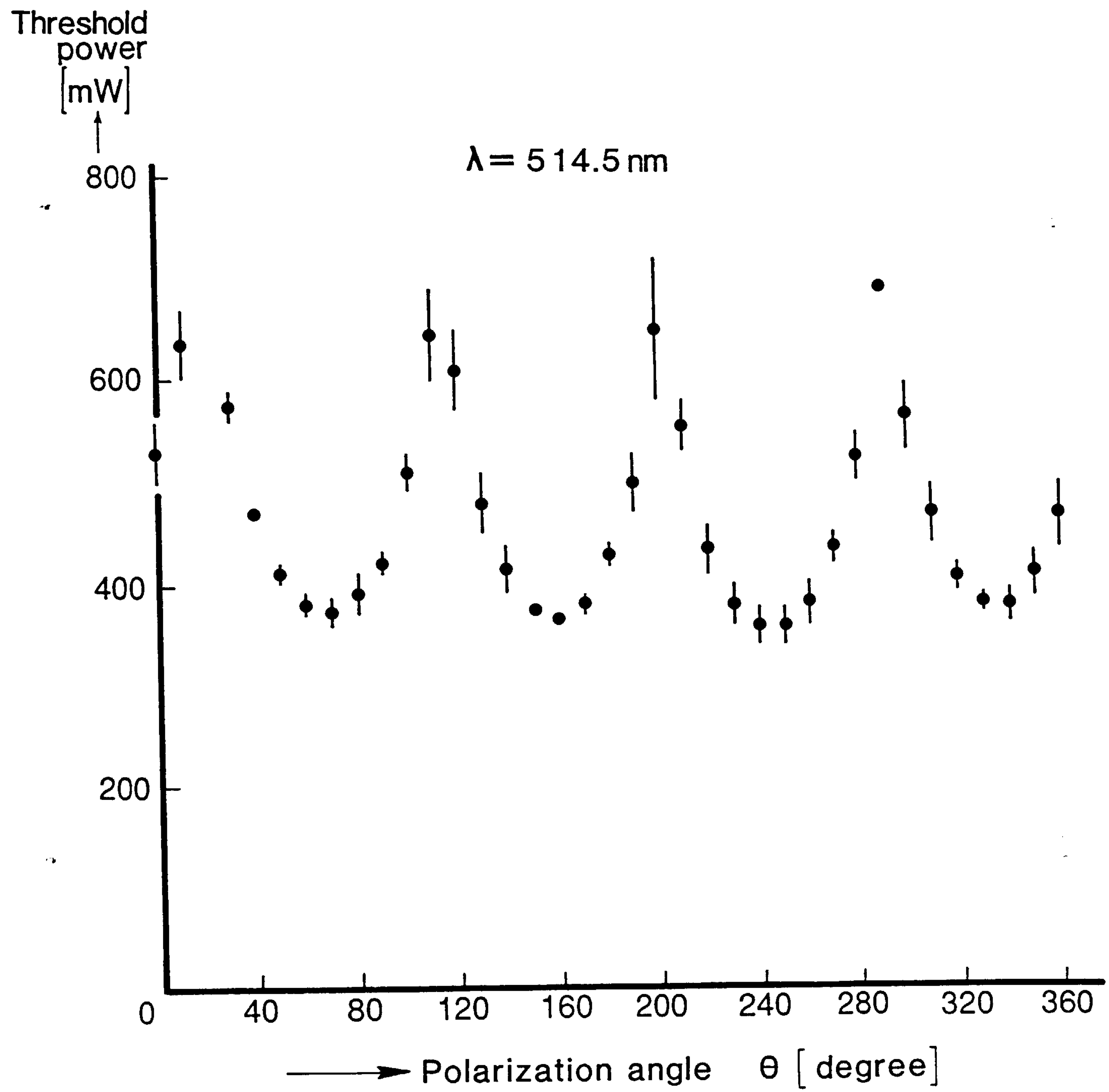
• Non polarization-preserving single mode fiber
• Polarization-preserving single mode fiber
Linear birefringent fiber $\beta_x \neq \beta_y$
$n_p < n_{cl}$
Side-pit fiber
$n_t = 1.0$
Side-tunnel fiber
Geometrical birefringent type
Bileaky type
Bow-tie
Panda
Stress-induced birefringent type
Core
Cladding
Jacket
Doped region
Circular birefringent fiber $\beta_R \neq \beta_L$
τ
τ
τ
τ

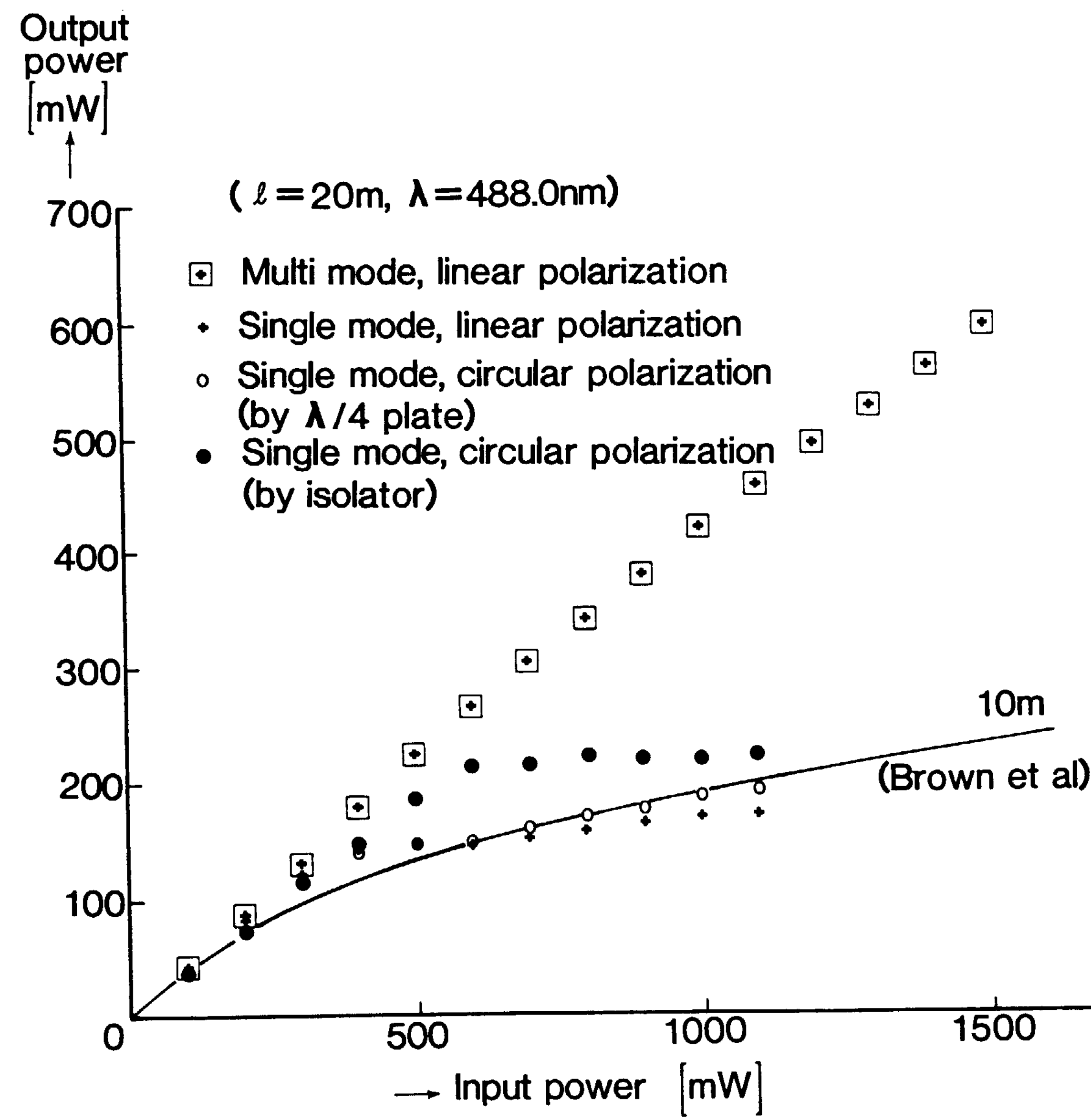


Polarization controller
Quartz plate
Laser
Coupler
Coupler
Spectrum analyzer
Spectrum analyzer
20 m PPSMOF

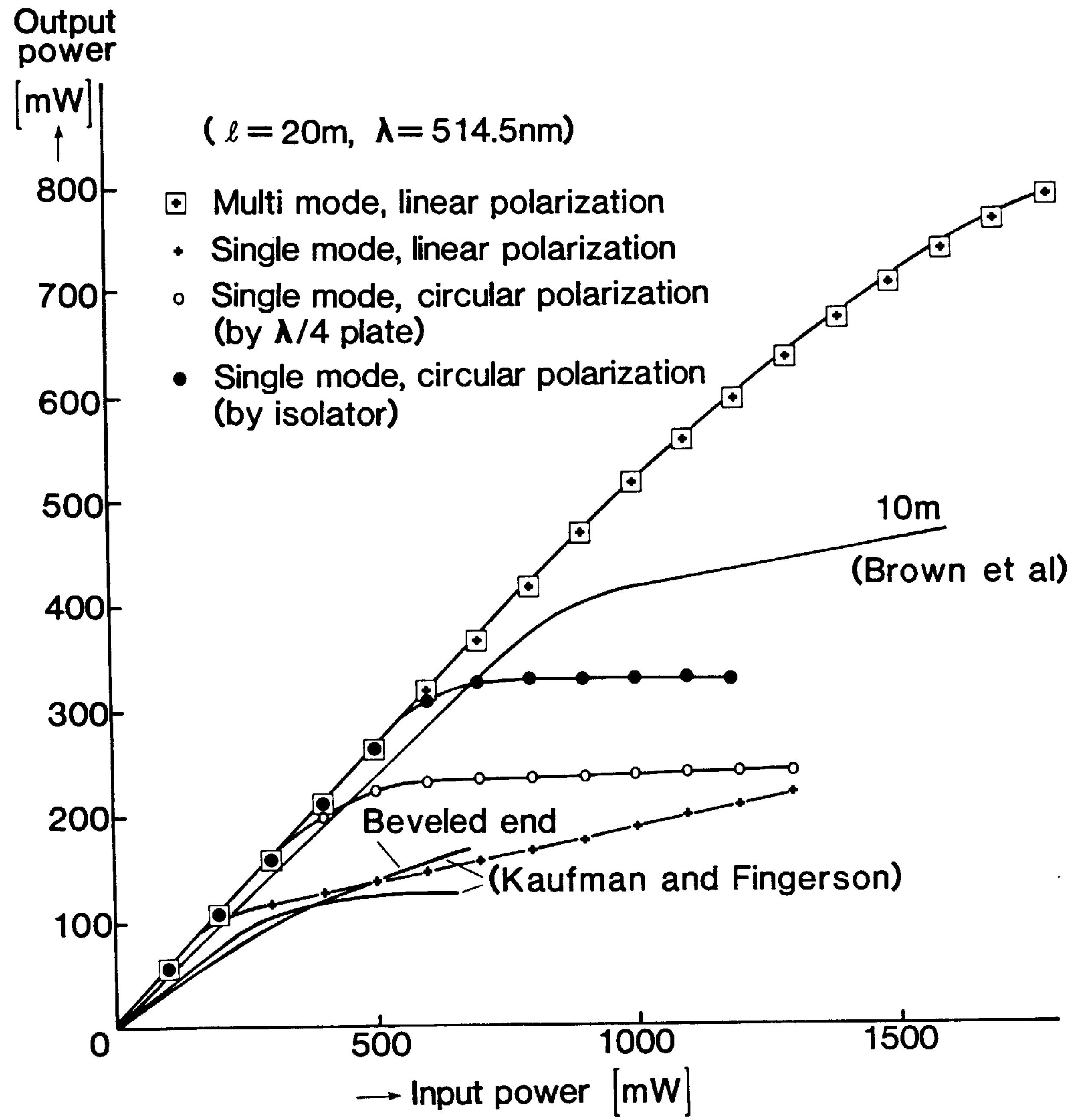

SBS
b
L
L
SBS
a
L
L


Threshold power [mW]
λ= 488.0 nm
800
600
400
200
0
40
80
120
160
200
240
280
320
360
Polarization angle θ [degree]


Threshold
power
[mW]
λ= 514.5 nm
800
600
400
200
0
40
80
120
160
200
240
280
320
360
Polarization angle θ [degree]



Output power [mW]
(ℓ = 20m, λ = 488.0nm)
Multi mode, linear polarization
Single mode, linear polarization
Single mode, circular polarization (by λ/4 plate)
Single mode, circular polarization (by isolator)
10m
(Brown et al)
700
600
500
400
300
200
100
0
500
1000
1500
Input power [mW]


Output power [mW]
(ℓ = 20m, λ = 514.5nm)
Multi mode, linear polarization
Single mode, linear polarization
Single mode, circular polarization (by λ/4 plate)
Single mode, circular polarization (by isolator)
800
700
600
500
400
300
200
100
0
500
1000
1500
10m
(Brown et al)
Beveled end
(Kaufman and Fingerson)
→ Input power [mW]