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ALL FIBRE 2×2 POLARISATION INSENSITIVE SWITCH

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Abstract

We report the development of a polarisation insensitive all fibre 2×2 acousto-optic switch based on twisting the waist of a null taper coupler. The polarisation insensitivity is better than 0.2 dB, the device requires a drive power of < 1 mW, and exhibits a switching time of < 50 μs and insertion loss of 0.1 dB.

Recently a new type of acousto-optic device based on four port null taper couplers has been demonstrated, and has been shown to be efficient as an optical switch, frequency shifter and tunable filter [1-3]. The coupler is a special type made from two fibres with diameters so mismatched that it does not actually couple any light. Light input via one fibre excites just the fundamental mode in the narrow waist of the coupler whereas light input via the other fibre excites just the second mode. In both cases the light propagates along the waist and returns to the original fibres at the output end of the coupler. However, in the case that a flexural acoustic wave propagates along the coupler, it causes a periodic refractive index perturbation in the waist. If a resonance condition is met (the acoustic wavelength matches the optical beat length between the modes) then light can couple between the modes. The main advantages of the null coupler are that it is a monolithic four-port device with a low insertion loss, low drive power requirement and a high conversion efficiency when compared to other acousto-optic devices [4,5]. The devices demonstrated so far, however, have been shown to be strongly polarisation dependent and this effect has to be suppressed for the device to be practical. In this paper we show that polarisation sensitivity can be overcome by twisting the waist of the null coupler. The effect is attributed to a combination of ellipticity of the taper waist and the requirement that the polarisation beat length between the higher order modes exceeds the twist pitch. The fact that both of these conditions are violated for taper waists having a diameter < 6 μm means that the technique is not suitable for narrow band filters and frequency shifters, but is suitable to overcome the problem of polarisation dependance when used as a broadband switch.

In a single mode fibre, birefringence arises from the difference in the propagation constants of the two orthogonally polarised fibre modes. This difference is caused by a combination of core ellipticity (form birefringence)[6] and an associated thermal stress asymmetery (stress birefringence) [7]. One solution to overcome the problem of birefringence in single mode fibres has been to spin the preform [8,9] during fibre drawing to impart a permanant twist to the fibre and thus restore an average circular symmetery to the waveguide structure. If the spin rate, ξ (rad/m), is large compared to the birefringence, $\Delta\beta$ (rad/m), the magnitude of the birefringence oscillations becomes negligibly small and the apparent birefringence becomes [8]:

$$R(z) \approx \frac{\Delta\beta}{(\xi-\alpha)} \sin[(\xi-\alpha)z] \tag{1}$$

where α is the twist induced birefringence (rad/m) given by $\alpha = \xi g'$ and where g' is the proportionality constant for twist induced optical activity and has the value of 0.073 for silica. In the case of a null coupler the dominant effect giving rise to the polarisation splitting is different. For a null coupler there exists a large refractive index variation (silica to air) across the waveguide and this means that the taper waist is not weakly guiding, unlike the familiar core-cladding waveguide previously described. Whilst ellipticity and thermal stress are contributing factors to the birefringence, the principal effect is attributed to the change in V value and which is determined by the waist of the null coupler. Nevertheless, it is anticipated that the effect of birefringence in a null coupler can be overcome by twisting the coupler after fabrication.

An acousto-optic device based on a null coupler was made using standard telecommunications fibre, with a diameter of 125 μm. The coupler was made by stretching two fibres together in an oxybutane flame, and where one fibre had initially been pretapered to a diameter of 90 μm. For the chosen acoustic frequency of 1 MHz the required waist diameter can be calculated as 12.7 μm [1]. The final coupler waist was 8 mm long, had an excess loss of 0.1 dB and a maximum splitting ratio of 1:1000. The acoustic wave was generated by a piezoelectric (PZT) disk driven by a rf electrical supply and was coupled to the fibres by a conical horn. For an electrical drive power of 1 mW the conversion efficiency was 98 %.

For the untwisted device the output spectra versus wavelength are shown in Figure 1. The throughput spectrum reveals two principal dips, and the coupled spectra two peaks at the same corresponding wavelength. The spacing of 60 nm between the peaks, implying a beat length of 9 mm between the polarisation states, is close to the expected polarisation splitting of 50 nm. The side peaks are attributed to lack of uniformity along the final interaction length. Consequently when twisting the 8 mm fused interaction length of the null coupler by a number of turns, the twist pitch becomes short compared to the polarisation beat length and eqn. (1) holds. This effect is illustrated in Figure 2, where the wavelength dependence of the device when twisted by two revolutions is monitored. For this case the output spectra reveal a single 50 nm bandwidth dip for the throughput and a corresponding single peak for the coupled light at an intermediate value in relation to the polarisation states in Figure 1.

Confirmation that the device is polarisation insensitive was achieved by first launching laser light at 1550 nm through a polarisation controller and bulk optic half-wave plate, and then monitoring the light output via the throughput and coupled output ports at a detector. The effect of polarisation sensitivity for the untwisted device is shown in Figure 3(a). Rotating the half-wave plate by 45 degrees reduces the coupled output light by 17 dB on account of exciting the orthogonal polarisation state. However, in the case that the device is first rotated by two revolutions of twist, Figure 3(b), light monitored at the coupled output port is reduced only by 0.2 dB and indicates the polarisation insensitivity of the device.

In order to illustrate the null coupler as a polarisation independent switch the acoustic drive frequency was first tuned from 1 MHz to 1.01 MHz such that the resonant wavelength in Figure 3 was 1550 nm. The time response of the switch, Figure 4, was measured by modulating the rf drive with a square wave. The switch changes state in 40 μs, which compares well with the 46 μs predicted in reference 1. The time lag between the rf signal and the start of switching is the time that the acoustic wave takes to travel from the transducer through the horn and along the fibres to the coupler. The net effect is a time delay of ~ 100 μs between the electrical signal and the completion of optical switching. Any fluctuation in the output on account of rotating the half-wave plate and thus exciting the orthogonal polarisation state was less than 5 % in all cases.

We have demonstrated for the first time a polarisation independent acousto-optic device based on a null coupler. It has been shown that by twisting the fused interaction region the polarisation sensitivity is reduced typically from 17 dB to 0.2 dB. The device has a low drive power requirement, low insertion loss and a conversion efficiency of 100%. It is likely that the effect will be restricted to waist diameters > 10 μm, otherwise the requirements of the polarisation beat length being greater than the spin pitch, and a non circular waist are difficult to satisfy. However, for switching applications where frequency shifts < 2 MHz are sufficient, it is thought that twisting will prove fundamental in order to overcome the problem of polarisation sensitivity.

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References

1. T. A. Birks, D. O. Culverhouse, S. G. Farwell, and P. St. J. Russell, "2x2 single-mode fibre routing switch", Opt. Lett., vol.21, pp. 722-724, 1996.
2. D. O. Culverhouse, S. G. Farwell, T. A. Birks, and P. St. J. Russell, "Four port fused taper acousto-optic devices using standard telecommunications fibre", Electron. Lett., vol. 31, pp. 1279-1280, 1995.
3. D. O. Culverhouse, S. H. Yun, D. J. Richardson, T. A. Birks, S. G. Farwell,, and P. St. J. Russell, "All fibre acousto-optic tunable filter based on a null coupler", ECOC'96, WeP.27.
4. B. Y. Kim, J. N. Blake, H. E. Engan, and H. J. Shaw, "All fibre acousto-optic frequency shifter", Opt. Lett., vol. 11, pp. 389-391, 1986.
5. M. Berwick, and D. A. Jackson, "Coaxial optical-fibre frequency shifter", Opt. Lett., vol.17, pp. 270 - 272, 1992.
6. Schlosser, W. O., "Delay distortion in weakly guiding optical fibres due to elliptical deformation of the boundary", Bell Syst. Tech. J., vol. 51, pp. 487-492, 1972.
7. A. J. Barlow, and D. N. Payne, "The stress optic effect in optical fibres", Jn. Quantum. Electron., vol. QE-12, pp. 834-839, 1983.
8. A. J. Barlow, J. J. Ramskov-Hansen, and D. N. Payne, "Birefringence and polarisation mode dispersion in spun single mode fibres", Appl. Opt. Lett., vol.20, pp. 2962-2968, 1981.
9. A. J. Barlow, J. J. Ramskov-Hansen, and D. N. Payne, "Anisotropy in spun singlemode fibres", Electron. Lett. vol.18, pp. 200-202, 1982.

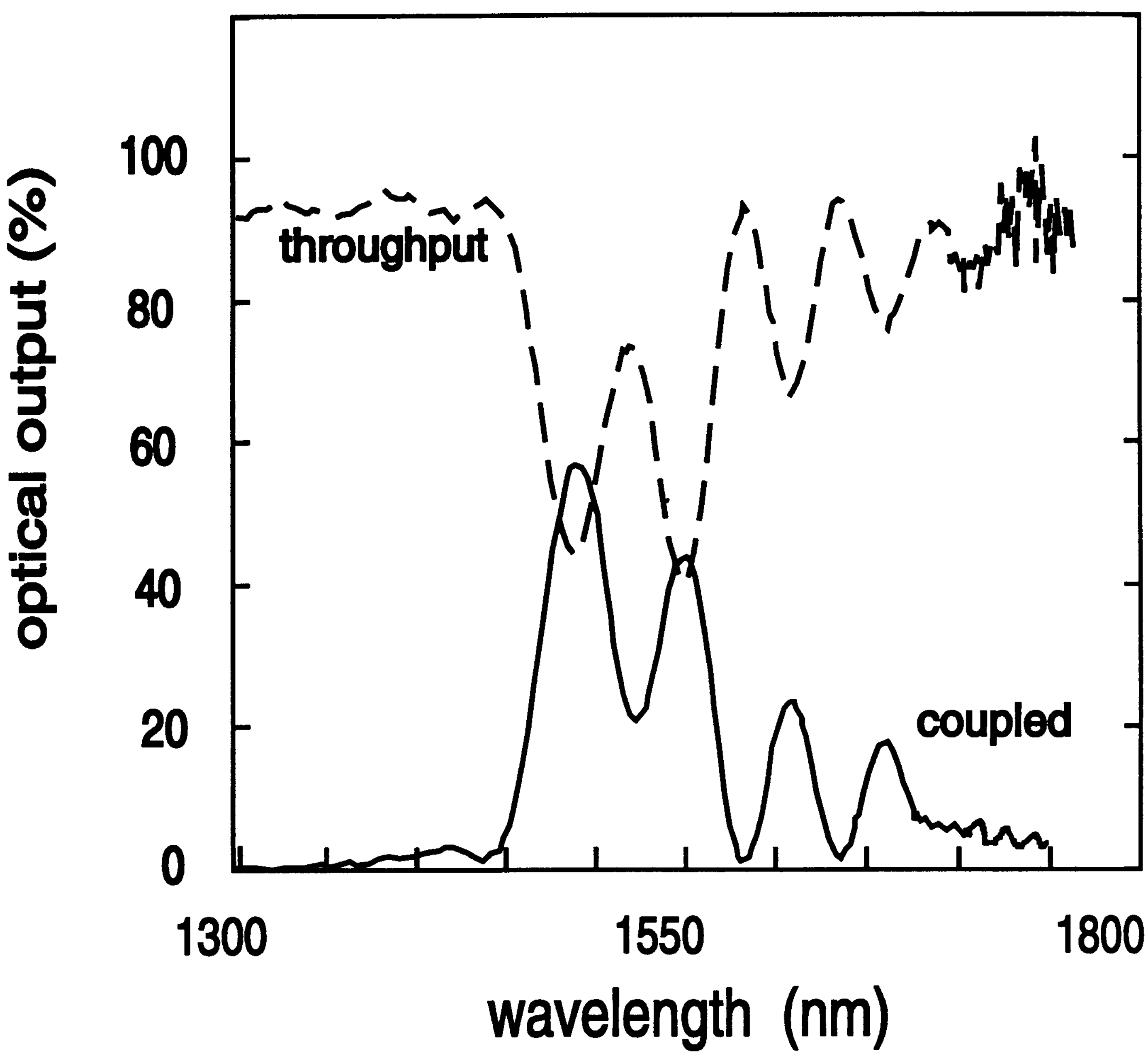
Figure captions

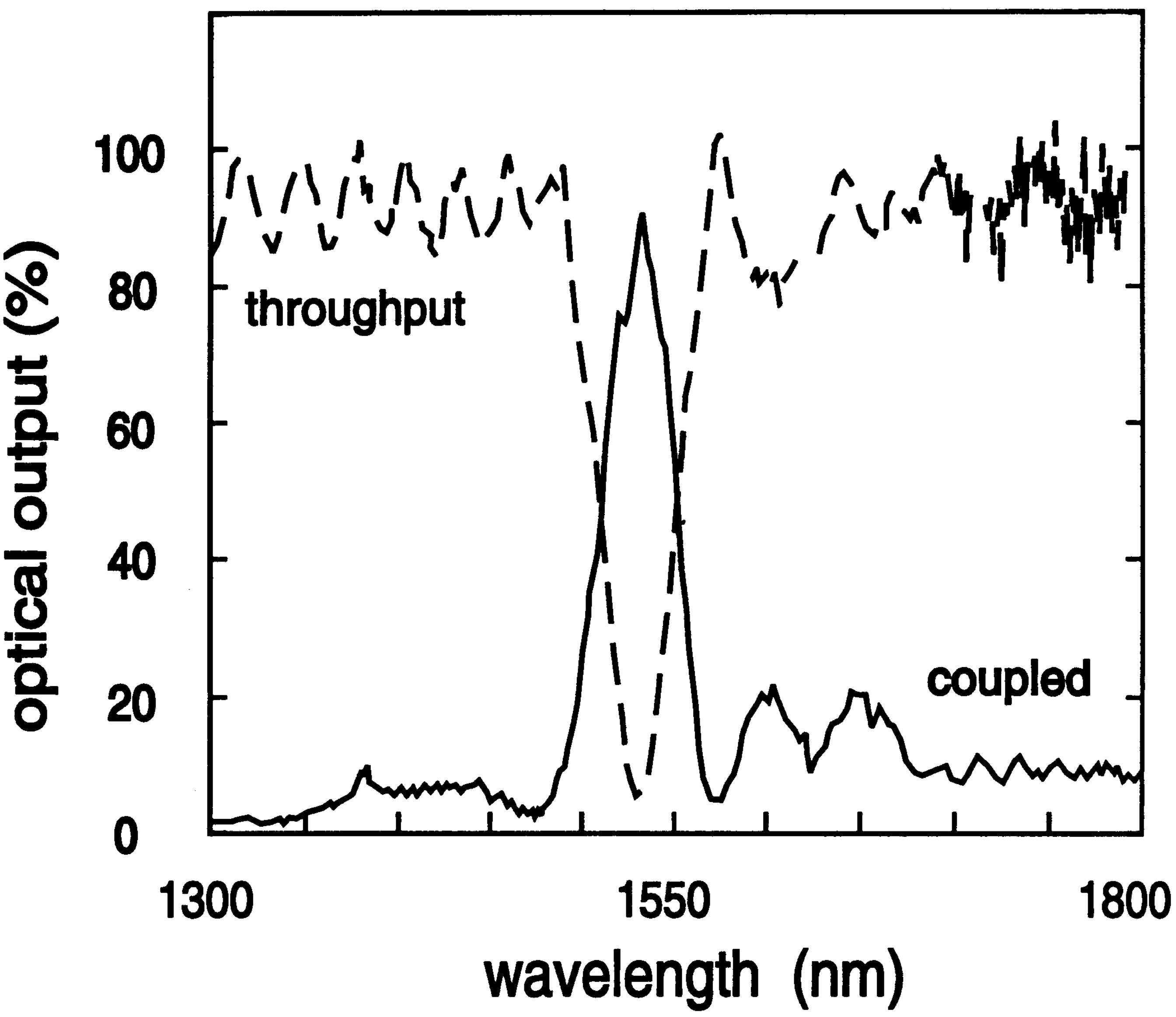
1. Normalised output spectra of the untwisted device: (i) throughput and (ii) coupled light. The polarisation states correspond to peaks at 1550 nm and 1490 nm, and where the sidelobes are attributed to non-uniformity along the taper length.

2. Normalised output spectra for 2 revolutions of twist: (i) throughput and (ii) coupled output light. The single peak at 1530 nm corresponds to an intermediate value given by the two peaks in Figure 1.

3. Throughput (○) and coupled (●)optical outputs of the null coupler versus half-wave plate rotation: a) untwisted and b) for two revolutions of twist.

4. Time variation of the optical power in each output of the polarisation insensitive switch. The rf drive is turned on at t = 0.


throughput
coupled
optical output (%)
0
20
40
60
80
100
1300
1550
1800
wavelength (nm)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0
20
40
60
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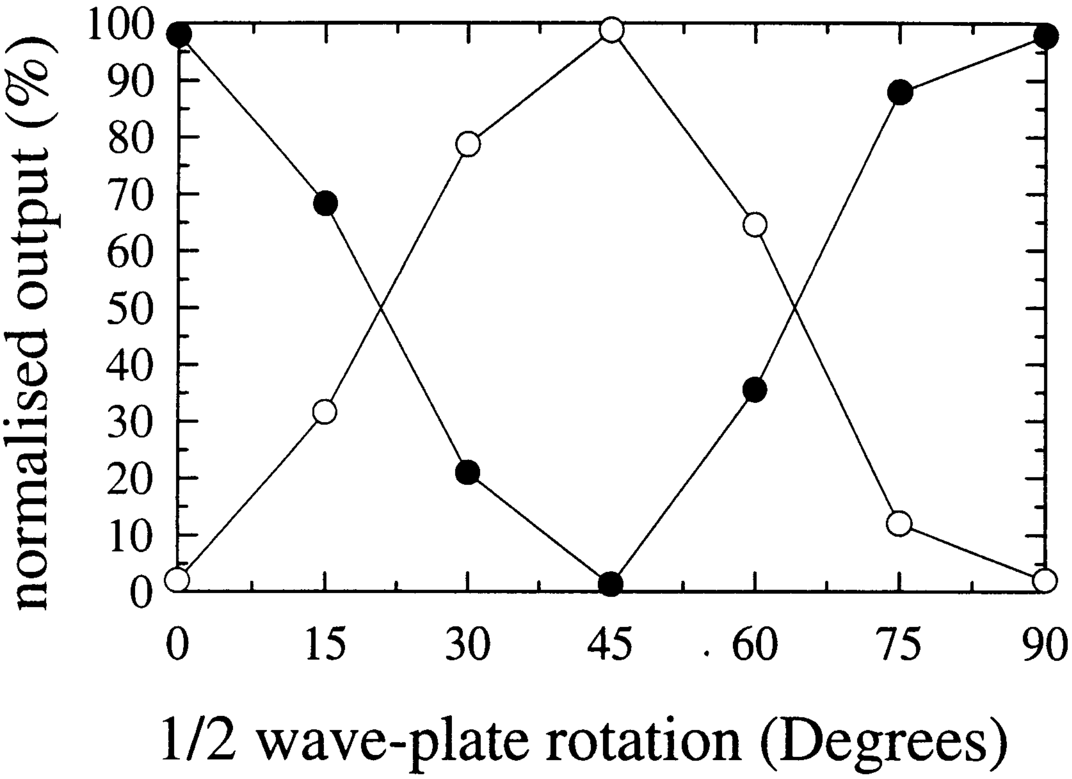
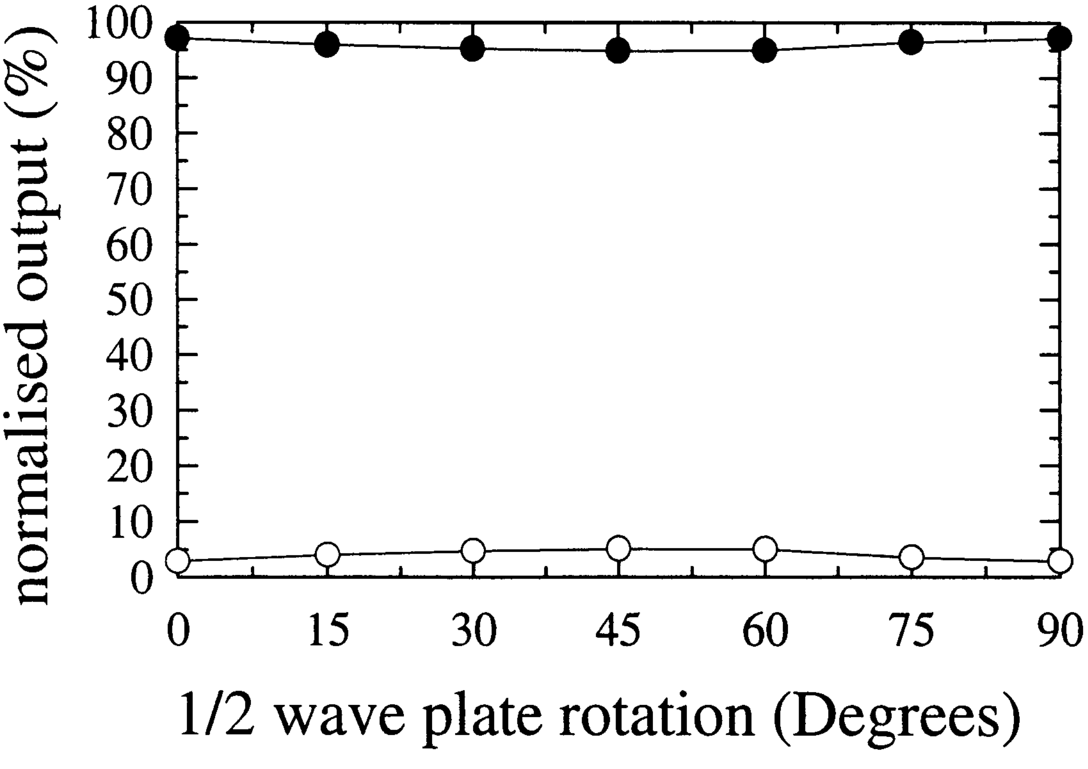
throughput
coupled
1300
1550
1800
wavelength (nm)



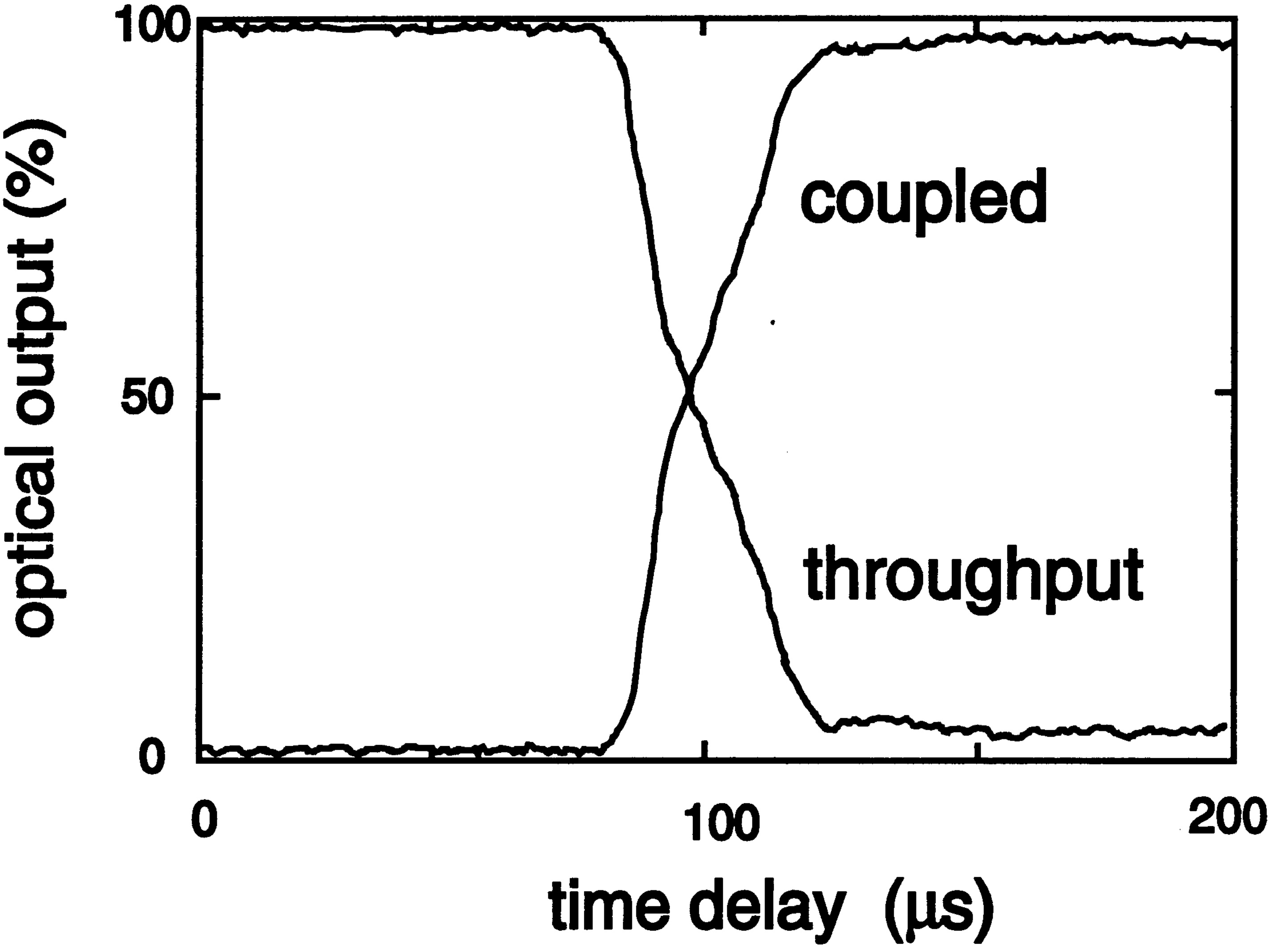
normalised output (%)
100
90
80
70
60
50
40
30
20
10
0
0
15
30
45
60
75
90
1/2 wave-plate rotation (Degrees)

(a)



normalised output (%)
100
90
80
70
60
50
40
30
20
10
0
0
15
30
45
60
75
90
1/2 wave plate rotation (Degrees)

(b)


100
50
0
optical output (%)
coupled
throughput
0
100
200
time delay (μs)