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770

LOW POWER ACOUSTO-OPTIC DEVICE IN TAPERED SINGLE-MODE FIBRE

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Abstract

We report a new acousto-optic device based on tapered single-mode fibre. Since the overlap between acoustic and optical waves is complete, very little acoustic power (less than 1 microwatt) is required.

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A number of acousto-optic fibre devices have been described previously[1,2,3]. Here we report a new acousto-optic device based on tapered single-mode fibre (Fig.1). In the taper, the fundamental mode spreads out from the core to fill the narrow uniform waist, which also guides many higher-order cladding modes. A unidirectional flexural acoustic wave is excited in the taper using a PZT disc and concentrator horn fixed to the fibre near the taper. Its frequency f is adjusted to match the acoustic wavelength to the beatlength between fundamental and second modes in the waist, causing light to couple between them. The taper transition acts as an additional acoustic concentrator. In the present form, light coupled to the second mode by the acoustic wave remains in the cladding downstream of the taper and is absorbed by the fibre coating, while light left in the fundamental mode is recaptured by the fibre core. The device therefore functions as an amplitude modulator or tunable filter.

Both modes fill the fibre at the waist, so there is complete overlap between acoustic and optical waves, and hence a low acoustic power requirement. This contrasts with previous devices, where light is confined to a fibre core while the acoustic wave is not, so overlap is poor. Also, much less acoustic power is needed for a given displacement in a narrow taper waist than in a full-size fibre.

A fibre was tapered to give a narrow waist 50 mm long and about 6 μm diameter, with excess loss <0.3 dB. For light of wavelength $\lambda=633$ nm, acousto-optic resonance was centred at $f=1.94$ MHz. Light throughput is plotted against pk-pk flexural wave amplitude in Fig.2, and against optical wavelength for $f=2.05$ MHz in Fig.3. Theoretically, an acoustic amplitude of 8 nm should give zero throughput (100% mode conversion). This corresponds to an acoustic power of just 41 nW. The expected FWHM optical bandwidth is $\Delta\lambda=1.64$ nm. In fact the minimum throughput of 8% required an amplitude of 33 nm (acoustic power 700 nW), with $\Delta\lambda=50$ nm. This is explained by a 0.2 μm variation in the waist diameter along its length, together with some polarisation dependence, and is desirable for broadband operation.

The supplied RF power was about 0.5 mW. The low power requirement permits the use of an inefficient low-Q acoustic source, and allows wide tunability. The resonance wavelength could be tuned through a 350 nm range using the same PZT disc with f from 1.3 to 2.9 MHz.

Acousto-optic devices can function as frequency shifters, tunable filters, switches and modulators. The present device is not suitable as a frequency shifter, because the shifted light in the second mode is lost. This light could be recovered by mechanical mode-coupling, for example[1]. By using a narrower taper, resonance frequencies and hence frequency shifts of hundreds of MHz are possible.

In conclusion, tapered fibre is a versatile medium for efficient acousto-optic interactions. There is complete overlap between acoustic and optical waves, and different resonance frequencies are possible by changing the waist diameter.

References

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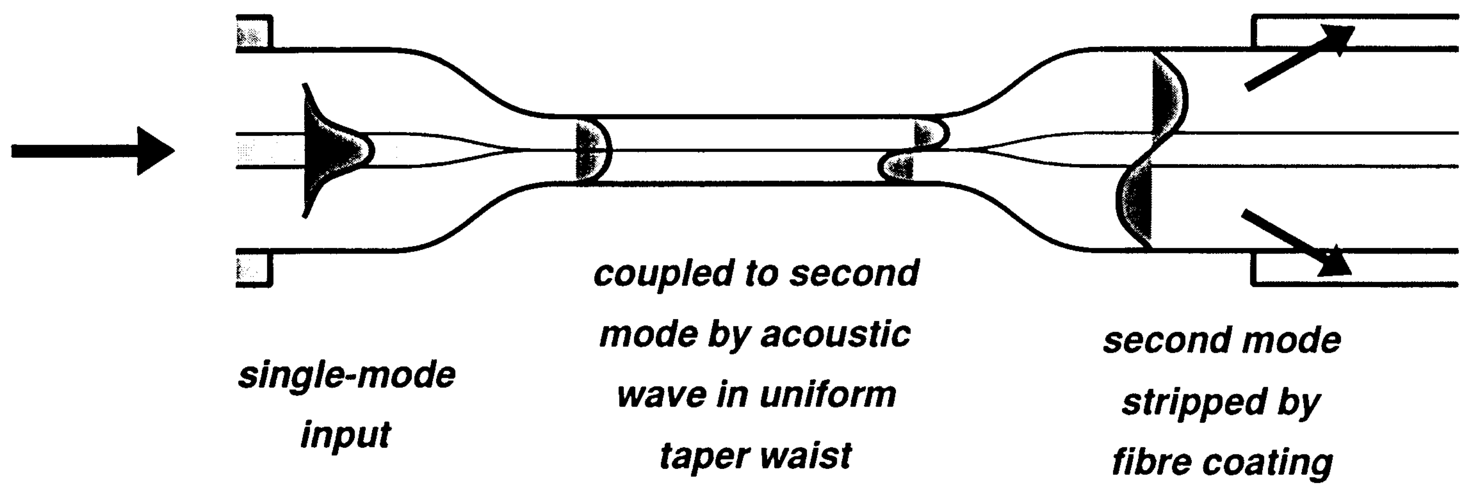
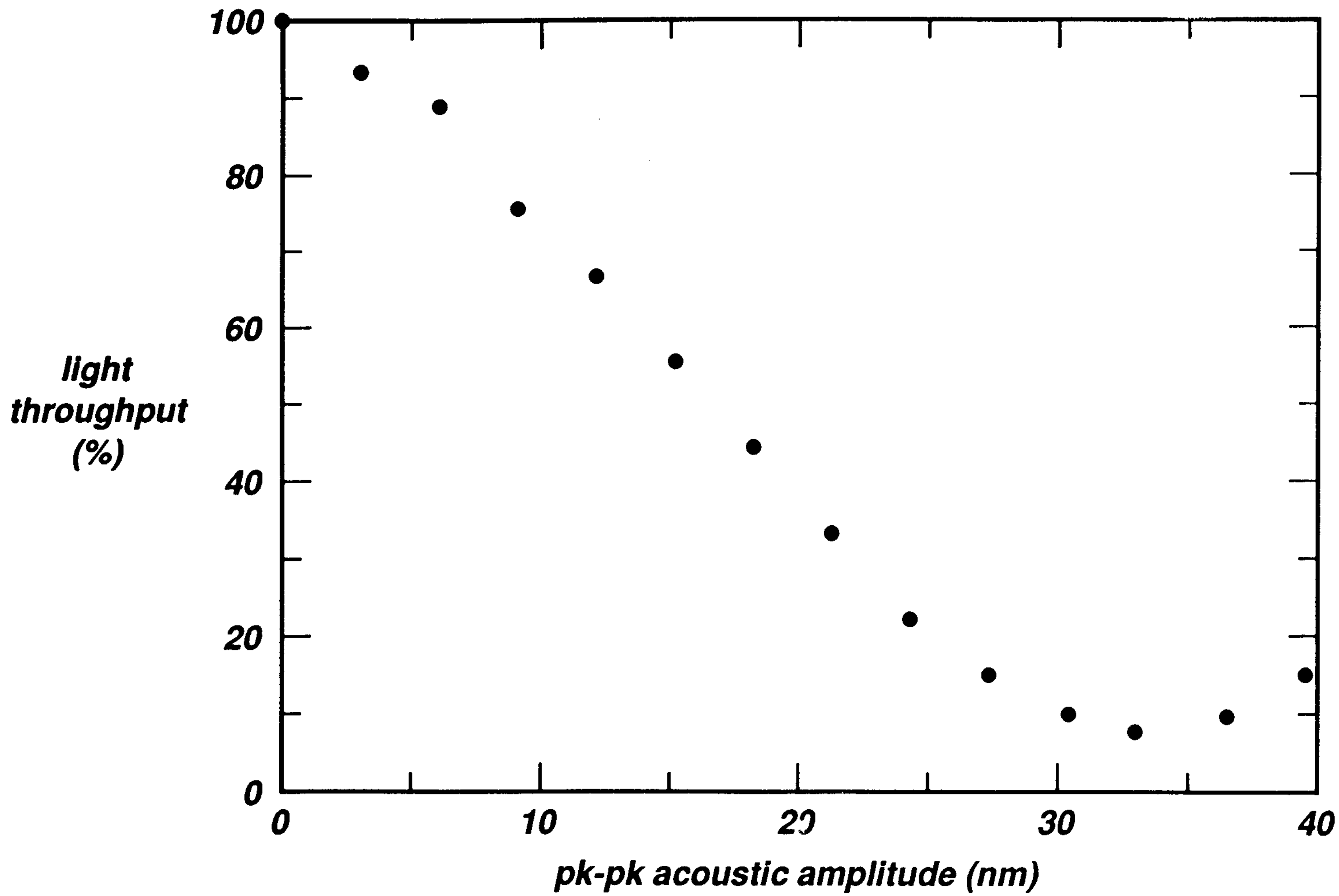
Figure Captions

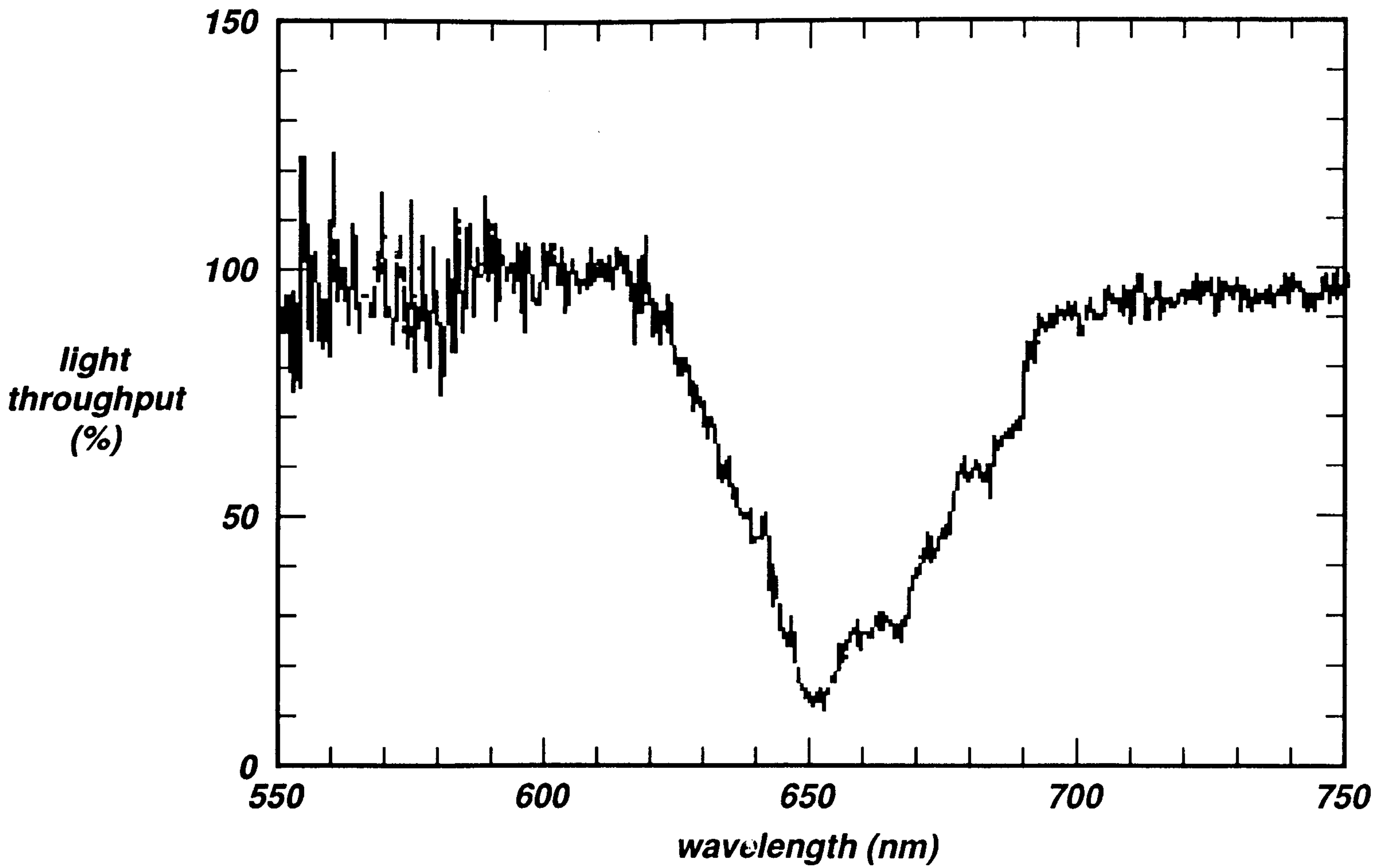
1. The acousto-optic interaction in a tapered single-mode fibre, with complete coupling from fundamental mode to second mode.

2. Device throughput versus acoustic amplitude (measured using an optical vibrometer) for $f=1.94$ MHz and $\lambda=633$ nm.

3. Device throughput versus optical wavelength for $f=2.05$ MHz, with acoustic amplitude adjusted to give minimum throughput at 650 nm.


single-mode input
coupled to second mode by acoustic wave in uniform taper waist
second mode stripped by fibre coating


light
throughput
(%)
100
80
60
40
20
0
0
10
20
30
40
pk-pk acoustic amplitude (nm)


light
throughput
(%)
150
100
50
0
550
600
650
700
750
wavelength (nm)