

Polarisation Control of Tapered Optical Fibre for Selective Whispering Gallery Mode Resonance Excitation

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Abstract

Tapered optical fibre evanescent light wave polarisation control is demonstrated with the utilisation of free-space optics polarised resolved set-up. TE- and TM-polarised lasing light discrimination of > 20 dB could be achieved with the proposed experimental setup and with tapered optical fibre of 2 μm waist diameter. Investigation on the performance of the proposed tapered optical fibre with whispering gallery mode (WGM) optical microresonators show distinguishable TE and TM group-mode families with high Q-factor and sharp wavelength dip contrast. The proposed setup is beneficial for photonics applications such as optical sensing and quantum physics where the polarisation state of light must be established.

1. Introduction

Tapered optical fibres, capable of achieving micro- and nano-scale waist diameter with low optical power loss [1], has emerged as a versatile tool in various photonics applications, including optical sensing and quantum physics. A key advantage lies in their tuneable evanescent field, which can be significantly enhanced to initiate strong light-matter interactions [2]. This capability is not only beneficial for optical spectroscopy and sensing but also provide an efficient method for coupling light into optical whispering gallery mode (WGM) resonators [2], [3], [4]. Maintaining low loss light transmission is important for avoiding the coupling of the fundamental mode to higher-order modes [5], typically achieved through adiabatic transitions with minimal taper angles [6]. Another consideration is that standard tapered optical fibres do not preserve the polarisation state of light [4], unlike costly and complex polarisation-maintaining fibres (PMFs) [7]. The fabrication process itself is also crucial, as achieving the desired taper profile depends on precisely controlling the length of the heated fibre [8], [9]. Despite these challenges, tapered optical fibres remain a highly efficient method for coupling light into optical microresonator cavities due to their ability to support large evanescent waves along the diminished core [4]. This paper introduces a robust and efficient technique for controlling the polarisation state of light in tapered optical fibres. The highly discriminating polarisation-resolved set-up allows for the distinct separation of the output light wave into transverse electric (TE) or transverse magnetic (TM) polarisations with an efficiency exceeding 20 dB. This capability offers significant advantage of coupling polarised light into high quality (Q) factor optical microresonator cavities which are important for increasing lightmatter interactions for enhanced optical experiment.

2. Fabrication of Tapered Optical Fibre and Polarised Experiment

The tapered optical fibres used in this experiment were fabricated by using the "flame brushing" technique as in shown Fig. 1 (a). The process began with a standard single-mode fibre (SMF) having an initial diameter of $D = 125 \mu\text{m}$. Before tapering, 2.0 cm section of the SMF's polymer coating was removed and the exposed glass cladding was cleaned with isopropanol alcohol. The SMF was then slightly strained and securely held by optical fibre clamps positioned on top of motorized translational stages. To facilitate the tapering process, the bare fibre section was heated and softened using a flame generated by a mixture of butane gas and compressed

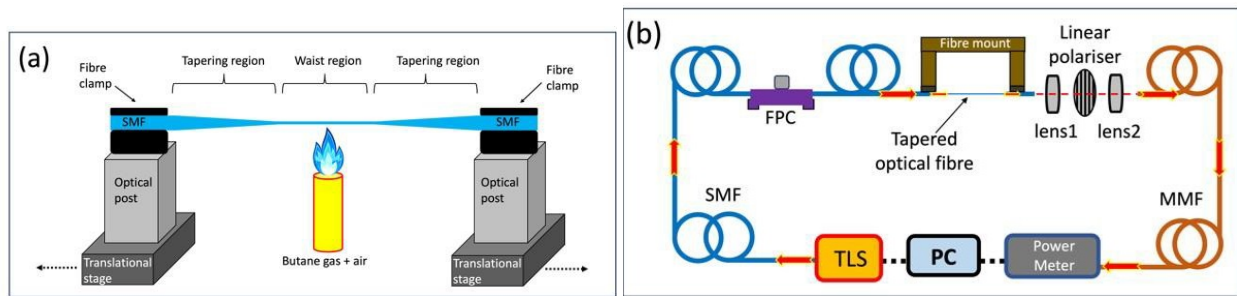


Figure 1. Flame brushing” technique process, (b) polarisation resolved set-up.

air. The motorised stages then moved in opposite directions, gently pulling the SMF while the central heated region was softened and drawn into a tapered optical fibre of diameter $D = 2 \mu\text{m}$. To test the tapered optical fibres, a polarisation-resolved experiment as in Fig. 1 (b) was set-up. The setup employed a broad tuneable laser source (TLS) with a narrow linewidth ($< 100 \text{ kHz}$) and high signal-to-noise ratio ($> 50 \text{ dB}$) as the primary light source. A computer (PC) was used to control the TLS that was synchronized to an optical power meter (-80 dBm to $+10 \text{ dBm}$). The output end of the tapered fibre, cleaved at its full diameter, had a lens (lens1) placed in front to collimate the light. A high-performance linear polariser ($> 45 \text{ dB}$) was positioned after lens1 to selectively filter TE- and TM-polarised light. A fibre polarization controller (FPC) was used to tune the polarisation of the tapered fibre’s evanescent wave. A second lens (lens2) focused the light into a multimode fibre (MMF) with its output end connected to the power meter for recording across a broad wavelength.

3. Results and Discussion

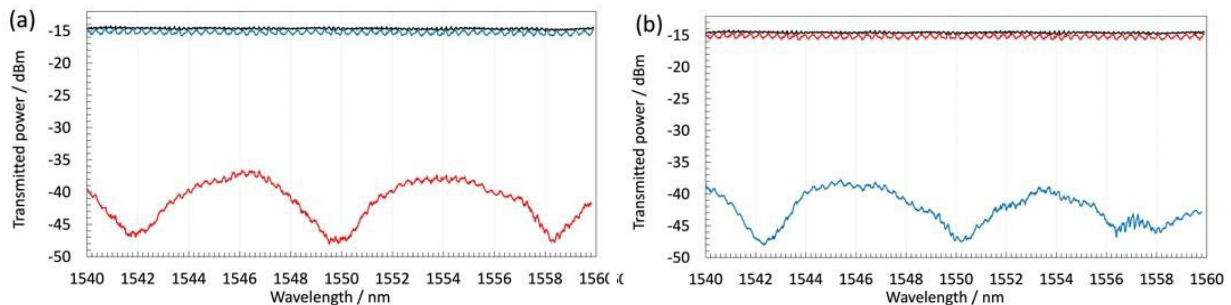


Figure 2. Transmitted output spectra with FPC tuned to (a) TE- and (b) TM-, and with the linear polariser set to TE (blue line), TM (red line) and removed from the system (black line).

Fig. 2 shows the measured transmission spectra of the fabricated tapered optical fibre with the linear polariser set to transmit TE polarisation (blue line), TM polarisation (red line), and with the linear polariser completely removed (black line). Fig. 2 (a) illustrates the transmission spectrum when the FPC was adjusted for linear TE polarisation. With the linear polariser aligned to the TE orientation (90°), the resulting output spectrum (blue line) exhibits a flat and continuous profile with power level around -15 dBm . When the linear polariser was oriented for TM transmission (0°), the output spectrum (red line) shows a sinusoidal pattern with peak power level of -35.5 dBm . This indicates a polarisation discrimination of over 20 dB between TE and TM of the tapered optical fibre, comparable to a polarisation-maintaining microsphere [7]. The similarity in the transmitted power level with the polariser (blue line) and without it (black line) confirms proper alignment to the TE orientation. A similar observation was made in Fig. 2 (b) when the FPC was tuned to linear TM polarisation. To test the proposed setup, an experiment was conducted where the tapered optical fibre was used as an excitation source in generating WGM resonances of an optical microsphere. Fig. 3 (a) illustrates coupling to a WGM optical microsphere ($D = 60 \mu\text{m}$). The TE-polarised transmission spectrum of the tapered fibre coupled to the microsphere cavity (baseline -14.5 dBm) is presented in Fig. 3 (b), revealing sharp resonant dips between 1540 and 1560 nm wavelength. Two distinct mode families with $> 17 \text{ dB}$ coupling efficiency were observed, with some broader dips suggesting WGM overlap. The microsphere exhibits high Q-factor (104), and the free spectral range (FSR) between TE-WG mode families were 8.5 nm . Fig. 3 (c) shows the TM-polarised transmission



spectrum with distinct resonant dips compared to the TE case, highlighting polarisation-dependent WGM excitation within the microsphere cavity. In summary, a method in tuning tapered optical fibres evanescent wave has been successfully demonstrated.

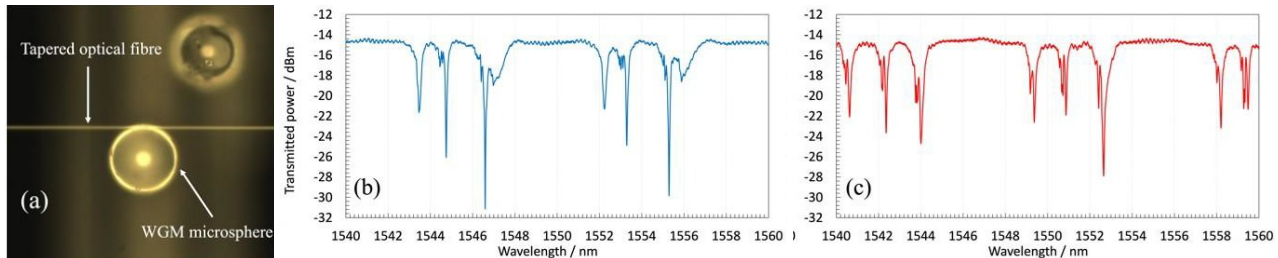


Figure 3. a) Coupling of tapered optical fibre to WGM microsphere. Transmitted spectral profile of microsphere with (b) TE-WGMs and (c) TM-WGMs

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