Room temperature self-assembly of mixed nanoparticles into photonic structures

Supplementary Information

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Supplementary Figures

Supplementary Figure S1. Microwire formation. a) Photograph of long microwires self-assembled on a glass slide of length $l = 7$ cm and dimensions $(10 \times 35) \, \mu m^2$; b) evaporative self-assembly formation of silica microwires optical images photographed with a microscopic CCD camera at 1 min, 3 min, 9 min, and 15 min after deposition of a drop of solution containing silica nanoparticles. As the solvent evaporates, silica nanoparticles aggregate and break into curled microwires. This shows a representative image of the microwire formation, although the image shown here is for smaller microwires the process is the same for all lengths. For longer wires ($l \geq 7$ cm) the curve is not great but they are straighter. For a drop of about ($\varphi \sim 15$ cm) in diameter, long and uniform microwires of length half the drop diameter ($0.5\varphi$) were produced with dimension $[(9.4, \sigma = 1.8) \times (36.7, \sigma = 6.8)] \, \mu m^2$ at one end and $[(9.8, \sigma = 1.5) \times (46.5, \sigma = 10.0)] \, \mu m^2$ at the other end with lengths ($l = 4.6, \sigma = 0.9$ cm) and a Tapering Aspect Ratio (TAR = dimension end$_1$/dimension end$_2$) $\sim (w_1/w_2 \sim 0.79; h_1/h_2 \sim 0.96)$, noting that that a TAR value of 1 relates to perfectly uniform wire in that dimension. All scale bar correspond to 5 mm.
**Supplementary Figure S2. Loss measurement setup.** The above setup was used to measure the optical loss of the microwires using the cutback method. Light (laser) is launched into the microwire using SMF-28 fibre and aligned using a XYZ stage. The output mode of the microwire is then projected through a 20X objective lens and an aperture onto a digital power meter and recorded.
Supplementary Figure S3. Microwire width, $w$, versus concentration [SiO$_2$] graph of small diameter droplets. The graph shows a linear trend in reducing the microwire width as a function of reducing SiO$_2$ concentration. All droplets were $V = 30$ µL deposited on the same glass slide. The graph shows the width of the microwire as a function of silica nanoparticle concentration. The solution of varying silica colloidal dispersion were made from a stock solution of 40 % w/w and diluted to 20, 10 and 5 % w/w in water. The droplets $V = 30$ µL were deposited on the same glass slide with a hand held micropipette and left to dry at ambient pressure and temperature ($T = 295$ K and $P = 1$ atm). The resultant wires were imaged with a microscope camera (Ziess ProGres) and the widths measured using the built-in software package.
Supplementary Figure S4. Modal profile in far field. Intensity profile of the output end of the microwire (SEM inset) with dimension of about (25 x10) μm², pumped with λ = 1550 nm EDFA source. The two spectra on each side of the modal profile image correspond to the intensity (arbitrary units, x-axis) of the modes over distance (y-axis). The modal profile was measured by coupling with λ = 1550 nm EDFA source to a microwire by butt-coupling to a standard SMF-28 carrier fibre. A 20X, 0.4 NA objective lens was placed at the out-put end of the microwire and the image from the objective was captured using a vidicon and a PC. The resulting intensity profile shows the complex modal interference from the many modes supported by the microwire; therefore we can confirm that the microwires of similar dimensions are all highly multi-mode with a large Ψ parameter. Scale bar in inset corresponds to 20 μm.
Supplementary Methods

Measurement of loss

The measurement of propagation loss is undertaken by the analogous cut-back measurement used to characterise optical fibres and other waveguide propagation losses. Supplementary Figure S2 summarises the method. A standard single mode optical fibre is used to launch light into the end face of the microwire – the position is adjusted to fill as many of the modes as possible. The microwire itself is fixed to two thin microscope cover slips to minimise loss leaking out. An aperture also filters out excess light that is not coupled into the microwire. Cutback measurement involves an initial measurement of input and output optical signals, cleaving the waveguide into a shorter length by hand using an aluminosilicate tile and repeating the measurements. By cleaving back losses arising from coupling into and out of the wire as well as leakage loss at the microscope slides is removed. (The ability to undertake cleaving is a clear measure of the robustness of the waveguides). The difference in loss provides information on the loss per unit length. Generally, the experimental error is reasonably small for single mode waveguides but for multimode waveguides of short length such as our microwires, this characterisation is more difficult because the coupling into the highly multimode structure is extremely sensitive to perturbations and not easily maintained between cuts. Different modal power distributions can give rise to different propagation losses. A less routine approach is to determine an average loss and a variance error across many microwires, arguably more suitable for comparing mass batch production methods such as that described here. Measurements are taken over ten similar wires and the mean obtained, along with the standard deviation which, for the multimode waveguide case, will typically be much larger than the cut-back experimental error of one wire under intended optical injection approaches.
In the text we present the average of ten similar wires and standard deviation (SD, $\sigma$) is presented, along with the lowest loss wire result. The former offers some assessment of similarity between microwires within the constraints of the system, whilst the latter is a better indicator of potential for improvement.