

Investigating the Use of Silver Nanofluids for Solar Collectors Connected to a Thermal Storage System

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Chapter 1

No Tables or Figures hence no additional data associated with this Chapter.

Chapter 2

Table 2-1. Values for parameters needed to estimate feasibility.

No additional data associated with this table

Table 2-2. Typical TES parameters. * - top value of 100 % impossible but quoted directly from International Renewables Agency IRENA (represents top of likely range).

No additional data associated with this table

Table 2-3. Scenarios considered.

No additional data associated with this table

Figure 2-1 Area of collector needed for Scenarios 1, 3 and 5. The average UK roof area of 15 m² ([Freeman et al., 2015](#)) is also shown.

Excel file: CDT 2019 paper data graphs.xlsx

Spreadsheet: size collector vs eff grph

Data: In spreadsheet: Solar collection - highlighted in yellow

Figure 2-2 Amount of energy captured at different values of collector efficiency η_c . The flat plate collector(FPC) and evacuated tube collector (ETC) values are from ([Ayompe and Duffy, 2013](#); [Ayompe et al., 2011](#)).

Excel file: CDT 2019 paper data graphs.xlsx

Spreadsheet: energy captured vs roof area

Data: In spreadsheet: Solar collection - highlighted in light orange

Figure 2-3 Size of thermal energy store (TES) needed for the six different scenarios for the three types of thermal storage, sensible thermal energy storage (STES), latent thermal energy store (LTES)

and thermochemical store (TCS). The ρ_{TES} values used are from ([International Renewable Energy Agency \(IRENA\), 2013](#)).

Excel file: CDT 2019 paper data graphs.xlsx

Spreadsheet: Store sizes grph

Data: In spreadsheet: Store sizes - highlighted in yellow

Table 2-4 Properties of STES materials. Data from ([Dincer and Rosen, 2011](#); [Gil et al., 2010](#)).

No additional data associated with this table

Table 2-5 Ideal PCM characteristics for LTES (adapted from ([Abokersh et al., 2018](#))).

No additional data associated with this table

Table 2-6 Properties of some PCMs. Data adapted from ([Agyenim et al., 2010](#); [Farid et al., 2004](#); [Zalba et al., 2003](#)).

No additional data associated with this table

Figure 2-4 Schematic of a salt hydrate thermochemical store (TCS) showing, (A) An open system and (B) A closed system with examples of both (adapted from ([de Jong et al., 2014](#); [Donkers et al., 2017](#); [Mamani et al., 2018](#))).

Power point file: Schematic of TCS.pptx

Image file: TCS schematic.jpg

Table 2-7 Properties of some proposed TCS materials. Data from ([Aydin et al., 2015](#)).

No additional data associated with this table

Figure 2-5 Illustration of the types of solar radiation incident on a surface of unit area (irradiance).

The angle of the surface to the horizontal is shown as θ .

Power point file: Irradiance types.pptx

Image file: Irradiance definitions.jpg

Figure 2-6 The wavelength (λ) dependence of the solar spectrum. The insert shows a magnification of the region from 300 nm – 1300 nm. Adapted from ([ASTM, 2012](#)).

Excel file: ASTMG173 solar spectrum.xlsx

Spreadsheet: graphs

Data: In spreadsheet: SMARTS2 - highlighted in yellow

Power point file: Figure 2-6.pptx

Image file: Figure 2-6.jpg

Figure 2-7 Schematics of light interactions with (A) A semi-transparent nanofluid and (B) A nanoparticle. Not to scale (the diameter of the NP at typically < 100 nm is significantly less than the depth of NF which is typically about 10 mm). Adapted from ([Honnerova et al., 2017](#); [Modest, 2003](#); [Otanicar et al., 2011](#)).

Power point file: Heat transfer and light interactions.pptx

Image file: light and DASC.jpg

Figure 2-8 Schematics of a FPC, (A) With a surface absorber and (B) A FPC, DASC containing a nanofluid. Typical dimensions are shown in brackets. Typical collector area = 1 m x 1.5 m per module ([Deng et al., 2016](#); [Hawwash et al., 2018](#); [Noghrehabadi et al., 2016](#)).

Power point file: FPCs 3D.pptx

Image file: FPC surface and DASC.jpg

Figure 2-9 Schematics of an ETC, (A) Using a surface absorber and (B) A volumetric absorber with a nanofluid. Typical dimensions and vacuum level shown in brackets. Typical length of glass tube = 1 m – 1.5 m ([Ayompe et al., 2011](#); [Mehta and Rane, 2013](#)).

Power point file: ETCs 3D.pptx

Image file: ETC surface and volumetric.jpg

Figure 2-10 Schematic of a heat pipe (HP) with a surface absorber. Adapted from ([Kumar et al., 2017](#); [Shafieian et al., 2019](#)). Typical dimensions shown in brackets ([Chopra et al., 2018](#); [Ozsoy and Corumlu, 2018](#)).

Power point file: Heat pipe.pptx

Image file: heat pipe schematic.jpg

Table 2-8 Types of colloids (adapted from ([Pashley and Karaman, 2004](#))).

No additional data associated with this table

Figure 2-11 Schematics of charged particle models showing (A) Helmholtz model, (B) Gouy-Chapman model and (C) SGC model. IHP is the inner Helmholtz plane and OHP the outer Helmholtz plane. The change in potential ψ is also shown. Adapted from ([Hunter, 1981](#); [Tiwari and Uzun, 2015](#)).

Power point file: Double layer theory.pptx

Image file: double layer theories.jpg

Table 2-9 Chapter 2 Summary.

No additional data associated with this table

Chapter 3

Table 3-1 Summary of main points covered in this and the proceeding Section.

No additional data associated with this table

Equation 3-4

Power point: Equations 3-4 and 3-5.pptx

Image file: Equation 3-4.jpg

Equation 3-5

Power point: Equations 3-4 and 3-5.pptx

Image file: Equation 3-5.jpg

Figure 3-1 SiO₂ coating protocol (shown in light blue) and parameters investigated (light green).

Power point: SiO₂ protocol and parameters varied.pptx

Image file: SiO₂ protocol and parameters varied.jpg

Table 3-2 Summary of SiO₂ coating of Ag methods Section.

No additional data associated with this table

Figure 3-2 Details of the solar simulator set-up showing (A) Schematic of solar simulator set-up, (B) Photograph of set-up (with the protective box open – showing 3 samples in the sample holder) and (C) Close up of 3 NF samples in the Perspex sample holder (Set-up A).

Power point file: Schematic of solar simulator.pptx

Image file: Solar simulator.jpg

Figure 3-3 Detail of (A) Sample holder and (B) ZEN0040 cuvette. All dimensions in mm.

Power point file: cuvette holder and cuvette.pptx

Image file: Cuvette holder and cuvette.jpg

Figure 3-4 Detail of cuvettes used for (A) Set-up A and (B) Set-up B.

Power point file: solar simulator cuvettes set up a and b.pptx

Image file: solar sim cuvettes set up a and b.jpg

Table 3-3 Comparison between solar simulator set-up A and set-up B. For an understanding of measurement sensitivity see uncertainty analysis (Section 3.10 and Appendix C.4).

No additional data associated with this table

Figure 3-5 Detail of flow cell. All dimension (in red) in mm. Diameters are internal diameters.

Power point file: flow cell.pptx

Image file: flow cell.jpg

Figure 3-6 Detail of experimental set-up to assess flow showing (A) Schematic of solar simulator set-up and (B) Photograph showing flow cell in the solar simulator. Red arrows denote the direction of flow.

Power point: Solar simulator flow.pptx

Image file: solar simulator flow.jpg

Table 3-4 Summary of Stability testing conditions and Subsections.

No additional data associated with this table

Table 3-5 Chapter 3 Summary.

No additional data associated with this table

Chapter 4

Figure 4-1 UV-vis spectra of Ag NS stabilised with TSCD and with TSCD-PVP. The average normalised data (Ab_{Norm}) for 3 concentrations of Ag TSCD NS (0.1 mM, 0.2 mM and 0.4 mM, number of samples $N = 9$) and for 4 concentrations of Ag TSCD-PVP NS (0.1 mM, 0.2 mM, 0.4 mM and 0.8 mM, $N = 12$) are shown. The insert shows how the absorption value changes with Ag concentration (for a 1 mm path length cuvette). All measured using UV-vis-1.

Excel file:UV vis Ag NS.xlsx

Spreadsheet: graph for report

Data: Main graph - In spreadsheet: 0.2 0.4 0.8 mM - highlighted in yellow, insert graph – In spreadsheet: concentration - highlighted in yellow

Power point file: Figure 4-1.pptx

Image file: Figure 4-1.jpg

Figure 4-2 TEM micrograph of Ag TSCD-PVP NS. Red scale bar = 20 nm.

Power point: TEM Ag NS TSCD PVP.pptx

Image file: Ag TSCD PVP NS initial.jpg

Figure 4-3 Amount of power absorbed P_{Ab} of the G173 ($G_{s,\lambda}(\text{dir} + \text{cs})$) by the NS NFs at different Ag starting concentrations and path lengths. The secondary vertical axis is for the G173 solar spectrum taken from ([ASTM, 2012](#)). The 10 mm path length data is calculated from the 1 mm data using the Beer Lambert law ([Sheffield Hallam University, 2019](#)).

Excel file:UV vis Ag NS.xlsx

Spreadsheet: AE grph

Data: In spreadsheet - Summarised Ab eff - highlighted in yellow

Table 4-1 Estimated η_{Ab} values for various NS NFs.

Excel file:UV vis Ag NS.xlsx

Data: In spreadsheet - Summarised Ab eff - highlighted in light orange (excel rows 556 – 558), sample details and path length in same spreadsheet row 3 columns C – G

Figure 4-4 UV-vis spectra for Ag NPr stabilised with TSCD. All measured on UV-vis-1. The average 0.1 mM ($N = 9$) and the average before centrifuging all measured with a 10 mm path length quartz cuvette. The data for the after centrifuging samples has been adjusted for volume and cuvette path length (original spectra recorded using $\frac{1}{4}$ volume samples and a 1 mm cuvette). The error bars show the range of results obtained at the maximum absorbance.

Excel file: UV vis Ag NPr.xlsx

Spreadsheet: Average TSCD grph

Data: In spreadsheet – Initial data - columns X, Y, AD – AH - highlighted in light green

Figure 4-5 UV-vis spectra for Ag NPr stabilised with TSCD and PVP. All measured on UV-vis-1 except the Ag NPr 25 mL samples (measured on UV-vis-IR-1). All the non-centrifuged samples measured with a 10 mm path length cuvette. The data for the after centrifuging samples has been adjusted for volume and cuvette path length (original spectra recorded using $\frac{1}{4}$ volume samples and a 1 mm cuvette). The error bars show the range of results obtained at the maximum absorbance.

Excel file: UV vis Ag NPr.xlsx

Spreadsheet: Average TSCD PVP grph

Data: In spreadsheet – Initial data - columns CG – CO - highlighted in light purple

Figure 4-6 TEM micrographs of (A) Ag TSCD-PVP NPr 50 mL, (B) Ag TSCD-PVP NPr after centrifuging and concentrating to $\frac{1}{4}$ volume, (C) Ag TSCD-PVP NPr 25 mL and (D) insert showing edge of Ag TSCD-PVP NPr 25 mL. All red scale bars = 100 nm.

Power point: TEM Ag NPrs TSCD PVP.pptx

Image file: TEM Ag NPr TSCD PVP initial.jpg

Figure 4-7 Summary of TEM size analysis for Ag TSCD-PVP NPr. The percentage of each particle type is shown on the primary vertical axis and the average size of each particle type on the secondary vertical axis.

Excel file: TEM Ag NPRs TSCD PVP initial.xlsx

Spreadsheet: percentages grph

Data: In spreadsheet – Percentages – rows 11 – 19, Columns B – E - highlighted in light orange

Figure 4-8 Amount of power absorbed P_{Ab} of the G173 ($G_{s,\lambda(\text{dir} + \text{cs})}$) by the Ag TSCD NPRs using a path length of 10 mm. The secondary vertical axis is for the G173 solar spectrum taken from ([ASTM, 2012](#)). The adjusted centrifuged samples are calculated assuming that the NPRs were re-dispersed in the same volume as the before centrifuged samples. For the actual after centrifuging NF, the 1 mm path length UV-vis-1 spectra have been adjusted to a 10 mm path length.

Excel file: UV vis Ag NPR.xlsx

Spreadsheet: Ag NPR TSCD AE grph

Data: In spreadsheet – Summarised Ab eff – columns A – F – highlighted in light orange

Figure 4-9 Amount of power absorbed P_{Ab} of the G173 ($G_{s,\lambda(\text{dir} + \text{cs})}$) with a 10 mm path length by the Ag TSCD-PVP NPR. The secondary vertical axis is for the G173 solar spectrum taken from ([ASTM, 2012](#)). The adjusted centrifuged samples are calculated assuming that the NPRs were re-dispersed in the same volume as the before centrifuged samples. For the actual after centrifuging NF the 1 mm path length UV-vis-1 spectra have been adjusted to a 10 mm path length.

Excel file: UV vis Ag NPR.xlsx

Spreadsheet: Ag NPR TSCD PVP Ae grph

Data: In spreadsheet – Summarised Ab eff – columns G – M – highlighted in light blue

Table 4-2 Estimated η_{Ab} values for various NPR NFs using a 10 mm path length.

Excel file: UV vis Ag NPR.xlsx

Data: In spreadsheet – Summarised Ab eff. Sample name in row 3, results rows 606 – 608 - highlighted in light purple

Table 4-3 Three selected recipes for the NFs to be used for the broadband silver NF absorber.

Excel file: Broadband absorber UV vis IR.xlsx

Data: In spreadsheet – Normalised 1350 – 300 - Sample details rows 1-5 and results in rows 1063 – 1066 - both highlighted in light orange

Figure 4-10 UV-vis-IR spectra for the final selected three NFs to be used in the broadband absorber. The error bars show the range of results obtained at the maximum absorbance for the three repeat synthesis. Measured using UV-vis-IR-1 and a 3 mL 10 mm path length

disposable cuvette. The mid λ and short λ samples have been diluted as detailed in Table 4-3.

Excel file: Broadband absorber UV vis IR.xlsx

Spreadsheet: selected recipe grph

Data: In spreadsheet – selected recipe data for thesis - data for graph highlighted in light orange

Figure 4-11 Amount of power absorbed P_{Ab} of the G173 ($G_{s,\lambda}(\text{dir} + \text{cs})$) with a 10 mm path length by the three component NFs. The secondary vertical axis is for the G173 solar spectrum taken from ([ASTM, 2012](#)). The results shown use the diluted components used for the UV-vis-IR measurements.

Excel file: AE calculations broadband.xlsx

Spreadsheet: components initial grph

Data: In spreadsheet – Initial results - data for graph highlighted in light orange

Figure 4-12 Calculated and measured spectra for the broadband mixture (30 % short λ , 20 % mid λ and 50 % long λ). The calculated spectra was obtained from the individual spectra for the component NFs. The error bars show the range of results obtained at the maximum absorbance for the three repeat synthesis. Measured using UV-vis-IR-1 and a 3 mL 10 mm path length disposable cuvette.

Excel file: Broadband absorber UV vis IR file 2.xlsx

Spreadsheet: mixture grph

Data: In spreadsheet – Mixture initial - data for graph highlighted in light orange

Figure 4-13 Amount of power absorbed P_{Ab} of the G173 ($G_{s,\lambda}(\text{dir} + \text{cs})$) with a 10 mm path length by the broadband mixture (calculated and measured). The secondary vertical axis is for the G173 solar spectrum taken from ([ASTM, 2012](#)).

Excel file: AE calculations broadband.xlsx

Spreadsheet: mixture initial grph

Data: In spreadsheet – Mixture initial - data for graph highlighted in light blue

Figure 4-14 TEM micrographs of (A) Short λ NF, (B) insert showing edge of short λ , (C) Mid λ NF, (D) insert showing edge of Mid λ , (E) Broadband mixture (30 % short λ , 20 % mid λ and 50 % long λ) and (F) insert showing edge of broadband mixture NPs. All red scale bars = 100 nm.

Power point: TEM broadband short and mid wavelength initial.pptx

Image file: TEM broadband short and mid wavelength.jpg

Figure 4-15 Summary of TEM size analysis for the broadband mixture and its component NFs. The percentage of each particle type is shown on the primary vertical axis and the average size of each particle type on the secondary vertical axis.

Excel file: measurement broadband(TEM).xlsx

Spreadsheet: Initial percents grph

Data: In spreadsheet – percents - highlighted in light purple

Figure 4-16 Calculated and measured spectra for the broadband mixture. The 25 mL batch data from Figure 4-12 have be included for ease of comparison. Measured using UV-vis-IR-1 and a 3 mL 10 mm path length disposable cuvette.

Excel file: UV-vis flow and consistency of batch.xlsx

Spreadsheet: broadband initial grph

Data: In spreadsheet – for graphs – data in columns Y to AC - highlighted in light purple

Figure 4-17 TEM micrographs of (A) Combined short λ NF, (B) insert showing edge of combined short λ , (C) Combined mid λ NF, (D) insert showing edge of combined mid λ , (E) Combined long λ NF, (F) insert showing edge of combined long λ , (G) Combined broadband mixture and (H) insert showing edge of combined broadband mixture. All red scale bars = 100 nm.

Power point: TEM combined broadband initial.pptx

Image file: TEM combined broadband.jpg

Figure 4-18 Summary of TEM size analysis for the combined broadband mixture and its component NFs (made using a 30 mL batch volume). The percentage of each particle type is shown on the primary vertical axis and the average size of each particle type on the secondary vertical axis.

Excel file: TEM consistency of batch.xlsx

Spreadsheet: initial percents grph

Data: In spreadsheet – percents rows 20 -29 - highlighted in light orange

Table 4-4 Chapter 4 Summary.

No additional data associated with this table

Chapter 5

Figure 5-1 Mean change in temperature (ΔT) as a function of SSL exposure time using set-up A.

Position in solar simulator = Back (B), middle (Md) and Front (F). The error bars show the range in results for ΔT at $t = 3600$ s.

Excel file: SSL Ag NPR and SiO₂ Ag NPR temperature data.xlsx

Spreadsheet: Ag NPR and water graph

Data: In spreadsheet – Mean sum delta T columns O – AA - highlighted in light orange

Figure 5-2 Mean change in temperature (ΔT) as a function of SSL exposure time using set-up B. The error bars show the range in results for ΔT at $t = 600$ s.

Excel file: Broadband and comp SSL temp PE data.xlsx

Spreadsheet: temp graph for thesis

Data: In spreadsheet – For thesis - columns J – T - highlighted in light orange

Table 5-1 Calculated values of $\eta_{\text{lamp}(330 \text{ nm} - 1100 \text{ nm})}$ and η_{PE} for the NFs tested using set-up B. For the calculation of $\eta_{\text{lamp}(330 \text{ nm} - 1100 \text{ nm})}$ for the broadband absorber the calculated spectral data has also been included (hence $N = 12$ rather than 9). The ANOVA results are also given where means that do not share the same letter are significantly different.

Excel file: Broadband and comp SSL temp PE data.xlsx

Data: In spreadsheet – PE % - columns Q – V and AC to AH - highlighted in light purple

Figure 5-3 Change in the UV-vis-IR spectra for the broadband absorber NF with exposure to an elevated temperature of 70 °C. The average spectra obtained at each time point is shown ($N = 6$ for the initial and $t = 0.5$ h time points whereas $N = 3$ for all other time points).

Excel file: Temperature stability uncoated.xlsx

Spreadsheet: broadband graph

Data: In spreadsheet – broadband - columns AP – BA - highlighted in light orange

Figure 5-4 TEM micrographs after 4 h at 70 °C of (A) Short λ NF, (B) Mid λ NF, (C) Long λ NF, and (D) Broadband mixture. All red scale bars = 100 nm.

Power point: TEM after temperature broadband.pptx

Image file: TEM after temp exposure.jpg

Figure 5-5 TEM analysis after 4 h at 70 °C for the broadband mixture and component NFs.

Excel file: TEM after temperature.xlsx

Spreadsheet: percents grph

Data: In spreadsheet – percents - highlighted in light orange

Figure 5-6 Change in λ_{\max} with exposure to simulated sunlight (SSL). The Ag TSCD-PVP NPr ct $\frac{1}{4}$ volume was tested using set-up A. The other NFs were tested using set-up B. 3 repeat samples were evaluated (for Ag TSCD-PVP NPr ct $\frac{1}{4}$ vol replica measurements were undertaken at some time points). The starting λ_{\max} is shown in brackets.

Excel file: SSL stability uncoated.xlsx

Spreadsheet: position grph

Data: In spreadsheet – position data – columns B – F, rows 19 - 88 - highlighted in light orange

Table 5-2 Change in Ab_{\max} following exposure to SSL for various NFs.

Excel file: SSL stability uncoated.xlsx

Data: In spreadsheet – UV data – highlighted in light orange

Figure 5-7 Change in the UV-vis-IR spectra for the broadband absorber NF (3 samples –denoted – 1, - 2 and – 3) with exposure to SSL using set-up B in the solar simulator. Measured using the UV-vis-IR-1 spectrophotometer (10 mm path length).

Excel file: SSL stability uncoated.xlsx

Spreadsheet: broadband grph

Data: In spreadsheet – Broadband – columns A – G - highlighted in light purple

Figure 5-8 TEM micrographs of (A) Ag TSCD-PVP NPr ct $\frac{1}{4}$ vol water - 4 initial, (B) Ag TSCD-PVP NPr ct $\frac{1}{4}$ vol water - 4 after 12 h SSL, (C) Ag TSCD-PVP NPr ct $\frac{1}{4}$ vol water - 5 initial, (D) Ag TSCD-PVP NPr ct $\frac{1}{4}$ vol water - 5 after 12 h SSL, (E) Ag TSCD-PVP NPr ct $\frac{1}{4}$ vol water - 6 initial, and (F) Ag TSCD-PVP NPr ct $\frac{1}{4}$ vol water - 6 after 12 h SSL. All red scale bars = 100 nm.

Power point: TEM before after SSL Ag NPrs ct.pptx

Image file: Ag NPrs before after SSL TEM.jpg

Figure 5-9 TEM analysis before and after 12 h SSL (using set-up A) for Ag TSCD-PVP NPr centrifuged and re-dispersed in $\frac{1}{4}$ volume of water. The value of λ_{\max} obtained is shown in brackets.

Excel file: TEM after SSL.xlsx

Spreadsheet: percentages grph

Data: In spreadsheet – percentages – rows 17 – 25 - highlighted in light purple

Figure 5-10 TEM micrographs after 0.5 h exposure to SSL of (A) Short λ , (B) insert showing edge of short λ , (C) Mid λ , (D) insert showing edge of mid λ , (E) Long λ , (F) insert showing edge

of long λ , (G) Broadband absorber NF, and (H) insert showing edge of broadband absorber. All red scale bars = 100 nm.

Power point: TEM broadband after SSL.pptx

Image file: After SSL broadband TEM.jpg

Figure 5-11 TEM analysis after 0.5 h SSL (using set-up B) for the broadband absorber mixture and its three component NFs.

Excel file: TEM after SSL.xlsx

Spreadsheet: broadband percents graph

Data: In spreadsheet – percentages – rows 17 – 26, columns P -T - highlighted in light orange

Figure 5-12 UV-vis spectra of Ag TSCD-PVP NPrs centrifuged and re-dispersed into $\frac{1}{4}$ volume of water before and after exposure to natural sunlight for either 2 weeks (trial 1) or 5 weeks (trial 2). Measured using UV-vis-1. The error bars show the range of results obtained at the maximum absorbance (the x error bars after sunlight exposure are excluded as it was difficult to determine λ_{\max}).

Excel file: Uncoated Ag NPr natural sunlight.xlsx

Spreadsheet: average graph

Data: In spreadsheet – for graphs – columns AS - BA - highlighted in light orange

Figure 5-13 UV-vis-IR spectra of the broadband absorber NF before and after being subjected to a flow rate of 0.238 mL s^{-1} for 8 h (3 repeats shown). Measured using a 1 mL plastic cuvette of 10 mm path length and UV-vis-IR-1.

Excel file: Effect of fluid flow.xlsx

Spreadsheet: flow only

Data: In spreadsheet – data – columns A - H - highlighted in light orange

Figure 5-14 UV-vis-IR spectra of the broadband absorber NF before and after being subjected to a flow rate of 0.238 mL s^{-1} for 6 h combined with an elevated temperature of $\approx 60 \text{ }^\circ\text{C}$ (2 repeats shown). Measured using a 1 mL plastic cuvette of 10 mm path length and UV-vis-IR-1.

Excel file: Effect of fluid flow.xlsx

Spreadsheet: flow and temp

Data: In spreadsheet – data – columns AC - AI - highlighted in light purple

Figure 5-15 UV-vis-IR spectra of the broadband absorber NF before and after being subjected to a flow rate of 0.238 mL s^{-1} for 7.5 h combined with simulated sunlight (SSL) for up to 4 h. Measured using a 1 mL plastic cuvette of 10 mm path length and UV-vis-IR-1.

Excel file: Effect of fluid flow.xlsx

Spreadsheet: flow and SSL

Data: In spreadsheet – data – columns BJ - BR - highlighted in light blue

Figure 5-16 UV-vis-IR spectra of the broadband absorber NF before and after being subjected to a flow rate of 0.238 mL s^{-1} for 5.5 h combined with an elevated temperature of $\approx 60 \text{ }^\circ\text{C}$ and SSL for 2.5 h (2 repeats). Measured using a 1 mL plastic cuvette of 10 mm path length and UV-vis-IR-1.

Excel file: Effect of fluid flow.xlsx

Spreadsheet: flow temp and SSL

Data: In spreadsheet – data – columns CR - CX - highlighted in light green

Figure 5-17 Photographs of the flow rig after use showing (A) The flow cell, associated piping and flask, (B) Detail of deposits on the side of the round bottomed flask reservoir, (C) The tubing exiting the peristaltic pump, (D) The bottom of the inlet tube placed in the round bottomed flask, (E) Detail of the connection tube at the top of the flow cell, (F) One of the thermocouples after testing, (G) Flow cell after testing, and (H) Detail of the connection tube at the bottom of the flow cell. The red arrows denote the direction of flow. All green scale bars = 10 mm.

Power point: Broadband appearance after flow SSL.pptx

Image file: Rig after flow testing.jpg

Figure 5-18 TEM analysis after flow, flow and elevated temperature ($60 \text{ }^\circ\text{C}$), flow and SSL and flow, elevated temperature and SSL for the broadband absorber mixture NF.

Excel file: TEM after flow.xlsx

Spreadsheet: initial percents grph

Data: In spreadsheet – percents – rows 13 - 21 - highlighted in light green

Figure 5-19 UV-vis spectra before and after exposure to a temperature of $70 \text{ }^\circ\text{C}$ for Ag TSCD-PVP NPrs centrifuged at 12,857 r.c.f. (10,000 rpm) for 30 minutes and re-dispersed into either $\frac{1}{4}$ volume of PG or water. All samples measured on UV-vis-1 with a 1 mm path length quartz cuvette. Average results shown. Error bars show range of results obtained at the maximum absorbance ($N = 3$).

Excel file: Uncoated in PG.xlsx

Spreadsheet: UV spectra grph

Data: In spreadsheet – Data – columns U - AG - highlighted in light green

Table 5-3 Chapter 5 Summary.

No additional data associated with this Table

Chapter 6

Figure 6-1 UV-vis-IR spectra before and after using the water-glass method to coat the Ag NPrs with SiO₂. All measured using UV-vis-1. The centrifuged results (¼ vol samples) have been adjusted for cuvette and volume. Average results shown (*N* = 3). Error bars depict range of results obtained at the maximum absorbance.

Excel file: Water glass UV-vis.xlsx

Spreadsheet: Initial grph

Data: In spreadsheet – data – columns R - AB - highlighted in light green

Figure 6-2 UV-vis spectra before and after exposure to SSL for 2 h using set-up A in the solar simulator. Measured using UV-vis-1. Average of three results shown with error bars depicting the range of results at the maximum absorbance.

Excel file: Water glass UV-vis.xlsx

Spreadsheet: after SSL grph

Data: In spreadsheet – data – columns DS - DW - highlighted in light orange

Figure 6-3 TEM micrographs after water-glass method of (A) Ag TSCD NPrs – 1 and water-glass SiO₂ in ¼ volume water initial, (B) After SSL for 2 h, (C) Ag TSCD NPrs – 3 and 5 x MPTMS, water-glass SiO₂ in water, and (D) in a mixture of water / 50 % PG. All red scale bars = 100 nm.

Power point: TEM water glass SiO₂.pptx

Image file: TEM water glass SiO₂.jpg

Figure 6-4 UV-vis spectra before and after application of the Stöber coating process investigating the effect of TEOS concentration. Measured using UV-vis-1 and a 10 mm path length quartz cuvette.

Excel file: Lismont stober TEOS procedure development UV-vis.xlsx

Spreadsheet: TEOS amount grph

Data: In spreadsheet – Data – columns A - F - highlighted in light orange

Figure 6-5 TEM micrographs after TEOS SiO₂ coating using (A) 16 mM TEOS, (B) 10 mM TEOS, (C) 8 mM TEOS, and (D) 1.6 mM TEOS. All using 20 μM MHA and 60 minutes TEOS reaction time. All red scale bars = 200 nm.

Power point: TEM optimisation of TEOS concentration.pptx

Image file: TEM opt of TEOS concentration.jpg

Figure 6-6 UV-vis spectra before and after application of the Stöber TEOS coating process investigating reducing the reaction time of the TEOS stage and increasing the concentration of capping agent MHA. Measured using UV-vis-1 and a 10 mm path length quartz cuvette.

Excel file: Lismont stober TEOS procedure development UV-vis.xlsx

Spreadsheet: Time and MHA amount grph

Data: In spreadsheet – Data – columns H - M - highlighted in light purple

Figure 6-7 TEM micrographs of (A) before, and (B - D) after TEOS SiO₂ coating using (B) 10 mM TEOS, 30 minutes, 20 μM MHA, (C) 10 mM TEOS, 30 minutes, 40 μM MHA, and (D) 10 mM TEOS, 15 minutes, 40 μM MHA. All red scale bars = 200 nm.

Power point: TEM optimisation of TEOS MHA and time.pptx

Image file: TEM opt of TEOS MHA and time.jpg

Table 6-1 Summarised UV-vis results for Ag TSCD-PVP NPrs before and after SiO₂ coating using the developed Stöber TEOS procedure (10 mM TEOS, 40 μM MHA, 30 minutes). Some samples were sub-divided after coating for subsequent testing, hence *N* after coating = 19 rather than 12.

Excel file: TEOS standard method as made UV vis.xlsx

Data: In spreadsheet – data – columns A – L, rows 5 - 9 - highlighted in light purple

Table 6-2 TEM analysis after SiO₂ coating using the developed Stöber TEOS procedure (SiO₂@Ag NPr, 10 mM TEOS, 30 minutes, 40 μM MHA). Average results for 9 samples shown (sample 7 has been excluded as was made using a lower batch volume). The average λ_{\max} from the UV-vis = 848 nm ± 48 nm (*N* = 9).

Excel file: Standard TEOS method TEM initial SiO2.xlsx

Data: In spreadsheet – Data – columns BJ – BP, rows 5 - 16 - highlighted in light purple

Figure 6-8 Amount of power absorbed P_{Ab} of the G173 ($G_{s,\lambda}(\text{dir} + \text{cs})$) with a 10 mm path length by the SiO₂@Ag NPrs (average for 7 samples shown). The power absorbed by centrifuged Ag

TSCD-PVP NPrs is also shown reproduced for ease of comparison from Figure 4-9. The secondary vertical axis is for the G173 solar spectrum taken from ([ASTM, 2012](#)).

Excel file: TEOS standard method as made UV vis.xlsx

Spreadsheet: power grph

Data: In spreadsheet – Summarised AE – columns A - D - highlighted in light orange

Figure 6-9 Mean change in temperature (ΔT) as a function of SSL exposure time using set-up A for water, SiO₂ only NF, and SiO₂@Ag NPrs. Position in solar simulator = Back (B), middle (Md) and Front (F). The error bars show the range in results for ΔT at $t = 3600$ s.

Excel file: SSL Ag NPr and SiO₂ Ag NPr temperature data.xlsx

Spreadsheet: SiO₂ SiO₂@Ag NPr grph

Data: In spreadsheet – SiO₂ and SiO₂@Ag NPrs – columns L - X - highlighted in light orange

Table 6-3 Summarised colloidal stability results for all SiO₂@Ag NPr NF samples stored in the dark at 4 °C for > 38 days.

Excel file: SiO₂ standard colloidal stability.xlsx

Data: In spreadsheet – Data – columns A – F, rows 4 - 9 - highlighted in light purple

Table 6-4 TEM analysis on SiO₂@Ag NPr re-dispersed into ¼ volume of water after storage for \approx 50 days in the dark at 4 °C. Average results for 3 samples shown. The average λ_{\max} from the UV-vis = 778 nm \pm 45 nm ($N = 3$).

Excel file: SiO₂ standard colloidal stability.xlsx

Data: In spreadsheet – TEM after – columns T – Z, rows 5 - 16 - highlighted in light pink

Figure 6-10 TEM micrographs of the standard TEOS SiO₂ coating after exposure to a temperature of 70 °C for 18 h showing (A) SiO₂@Ag NPr-10, and (B) SiO₂@Ag NPr-12, both NFs diluted to give an Ab_{\max} of \approx 0.8 au prior to temperature testing. All initially produced using 40 μ M MHA and 10 mM TEOS for 30 minutes. All red scale bars = 100 nm.

Power point: TEM standard TEOS temperature stability.pptx

Image file: TEM standard TEOS temperature stability.jpg

Figure 6-11 Change in λ_{\max} with exposure to simulated sunlight (SSL) for SiO₂@Ag NPrs re-dispersed into ¼ volume of water (compared to volume of starting NF). Tested using set-up A. The starting value of λ_{\max} is shown in brackets.

Excel file: SiO₂ standard SSL stability.xlsx

Spreadsheet: position grph

Data: In spreadsheet – time versus – columns H – K, rows 6 - 15 - highlighted in light pink

Table 6-5 Summarised results for SiO₂@Ag NPr NF re-dispersed into ¼ volume of water (compared to pre-coated NF volume) after 6 h exposure to SSL.

Ab_{\max} and λ_{\max} in Excel file: SiO₂ standard SSL stability.xlsx

Ab_{\max} and λ_{\max} Data: In spreadsheet – data - highlighted in light purple

Change in $\eta_{\text{lamp}(330 \text{ nm} - 900 \text{ nm})}$ in Excel file: lamp vs G173 solar broadband AE lamp cal.xlsx

Change in $\eta_{\text{lamp}(330 \text{ nm} - 900 \text{ nm})}$ Data: In spreadsheet – AE lamp spec - sample details row 4 columns HU – HW results columns HU – HW, rows 2413 – 2415 – highlighted in light purple

Table 6-6 TEM analysis on SiO₂@Ag NPr re-dispersed into ¼ volume of water after exposure to SSL for 6 h using set-up A in the solar simulator. Average results for 3 samples shown. The average λ_{\max} from the UV-vis = 592 nm ± 58 nm ($N = 3$).

Excel file: SiO₂ standard SSL stability.xlsx

Data: In spreadsheet – TEM after – columns AA – AF, rows 12 - 20 - highlighted in light purple

Figure 6-12 UV-vis spectra of SiO₂@Ag NPrs re-dispersed into ¼ volume of water compared to original NF volume before and after exposure to natural sunlight for either 2 weeks (trial 1) or 5 weeks (trial 2). Measured using UV-vis-1 and a 4 mm path length cuvette. The error bars show the range of results obtained at the maximum absorbance.

Excel file: SiO₂ standard NSL stability.xlsx

Spreadsheet: average grph

Data: In spreadsheet – data – columns AD – AL - highlighted in light pink

Figure 6-13 Effect of the reagents DMA and MHA on Ab_{\max} . Ab_{\max} has been normalised to the initial value for the Ag TSCD-PVP NPr centrifuged and re-dispersed in ¼ volume of water and adjusted to account for the NF concentration. Measured using UV-vis-1 and a 1 mm path length quartz cuvette.

Excel file: modifications to SiO₂.xlsx

Spreadsheet: role reagents grph

Data: In spreadsheet – role of reagents – columns AI – AN, rows 7 - 10 - highlighted in light pink

Figure 6-14 TEM micrographs of (A) SiO₂@Ag NPr, optimised procedure 8 mL NF volume, (B) SiO₂@Ag NPr, no MHA, ¼ volume DMA, (C) SiO₂@Ag NPr, 40 µM MHA, ¼ volume DMA and (D) SiO₂@Ag NPr, 160 µM MHA, ¼ volume DMA. 10 mM TEOS for 30 minutes in all cases. All red scale bars = 100 nm.

Power point: TEM modifications to SiO₂ DMA and MHA.pptx

Image file: TEM modifications to SiO₂ DMA and MHA.jpg

Figure 6-15 TEM micrographs of (A) SiO₂@Ag NPr, as synthesised, 1 minute reaction time, (B) SiO₂@Ag NPr, as synthesised, 5 minutes reaction time, (C) SiO₂@Ag NPr, 1 minute reaction time, after 18 h @ 70 °C and (D) SiO₂@Ag NPr, 5 minutes reaction time, after 18 h @ 70 °C. All red scale bars = 100 nm.

Power point: TEM modifications to SiO₂ TEOS timing.pptx

Image file: TEM modifications to SiO₂ TEOS timing.jpg

Figure 6-16 UV-vis-IR spectra for the broadband absorber before and after SiO₂ coating using the developed Stöber TEOS method and after storage in the dark at 4 °C. The supernatant after 3 h centrifuging at 16,168 r.c.f. (13,000 rpm) is also shown. Before storage measured using the UV-vis-IR-1 and after using UV-vis-IR-2 (10 mm path length).

Excel file: SiO₂ coated broadband.xlsx

Spreadsheet: after storage grph

Data: In spreadsheet – data – columns A – I, rows 16 onwards - highlighted in light pink

Figure 6-17 TEM micrograph of SiO₂@broadband NF. Red scale bar = 100 nm.

Power point: TEM SiO₂ coated broadband.pptx

Image file: TEM SiO₂ coated broadband.jpg

Figure 6-18 Photographs of (A) The broadband absorber NF, (B) The supernatant and (C) SiO₂@broadband NF after storage in the dark at 4 °C for 129 days. All green scale bars = 10 mm.

Power point: colloidal stability of SiO₂ broadband.pptx

Image file: colloidal stability of SiO₂ broadband.jpg

Table 6-7 Chapter 6 Summary.

No additional data associated with this Table

Chapter 7

Table 7-1 Summary of results obtained for the performance of the 7 NFs and water tested in this thesis. For further details of the results see Table 5-1, Table J.5 and Table J.9.

No additional data associated with this Table

Table 7-2 Summary of stability test results.

No additional data associated with this Table

Table 7-3 Summary of publications.

No additional data associated with this Table

Figure 7-1 Graphical abstract for publication 1, The Temperature Stability and Development of a Broadband Silver Nanofluid for Solar Thermal Applications ([Kimpton et al., 2021](#)).

Power point: graphical abstract paper 1.pptx

Image file: graphical abstract paper 1.jpg

Figure 7-2 Graphical abstract for publication 2, Silver nanofluids based broadband solar absorber through tuning nanosilver geometries ([Kimpton et al., 2020b](#)).

Power point: graphical abstract paper 2.pptx

Image file: graphical abstract paper 2.jpg

Figure 7-3 Graphical abstract for publication 3, Thermal performance and physicochemical stability of silver nanoprisms-based nanofluids for direct solar absorption ([Kimpton et al., 2020a](#)).

Power point: graphical abstract paper 3.pptx

Image file: graphical abstract paper 3.jpg

Appendix A

Figure A.1 Equilibrium curves for MgCl_2 and H_2O . The data for the MgCl_2 curves are taken from ([Donkers et al., 2017](#)) and the curve for H_2O is calculated from the steam tables for water ([Dean and Lange, 1999](#)). The reference lines at 12 mbar and 20 mbar represent suitable $p_{v(w)}$ values for hydration and dehydration respectively. The numbers in brackets are the change in the number of moles of water.

Excel file: thermodynamics.xlsx

Spreadsheet: MgCl2 grph

Data: In spreadsheet – for graphs – columns A, C, and H - M - highlighted in light orange

Table A.1 Ideal TCS Material Specification.

No additional data associated with this Table

Figure A.2 Equilibrium curves for K_2CO_3 , Rb_2CO_3 , CaC_2O_4 and H_2O . The data for the salt hydrate curves are taken from ([Donkers et al., 2017](#)) and the curve for H_2O is calculated from the steam tables for water ([Dean and Lange, 1999](#)). The reference lines at 12 mbar and 20 mbar represent suitable $p_{v(w)}$ values for hydration and dehydration respectively.

Excel file: thermodynamics.xlsx

Spreadsheet: graphs for thesis

Data: In spreadsheet – for graphs – columns A, B, C, E – G and K - M – additional columns not used in Figure A.1 highlighted in light purple

Appendix B

Table B.1 Studies on carbon-based NFs for solar applications.

No additional data associated with this Table

Table B.2 Studies on metal oxide based NFs.

No additional data associated with this Table

Table B.3 Studies utilising gold nanofluids.

No additional data associated with this Table

Figure B.1 Schematic of the three different types of silver hybrid nanofluids (A) Type 1 hybrid consisting of a mixture of different NP types, (B) Type 2 hybrid containing Ag NPs either coated or decorated with another material and (C) Type 3 hybrid containing another NP either coated or decorated with Ag.

Power point: Hybrid silver nanofluids.pptx

Image file: Hybrid silver nanofluids.jpg

Table B.4 Type 1 hybrid NFs investigated.

No additional data associated with this Table

Table B.5 Type 3 hybrid NFs investigated.

No additional data associated with this Table

Appendix C

Figure C.1 Comparison of the UV-vis and UV-vis-IR spectra from the different spectrophotometers used. UV-vis-1 = Varian Cary 300 Bio, UV-vis-IR-1 = Perkin Elmer Lambda 750S and UV-vis-IR-2 = AvaLight – Hal lamp and Avaspec -2048. Measured using a polystyrene macro-cuvette (2.5 mL – 4.5 mL volume) with a 10 mm path length.

Excel file: Spectroscope comparison.xlsx

Spreadsheet: grph

Data: In spreadsheet – Data – columns A - I highlighted in light purple

Table C.1 Measurements of $I_L / W \text{ m}^{-2}$ for set-up B in the solar simulator using a “ReRA System” calibrated silicon cell (area of cell = 3.6 cm²).

Excel file: ReRA System calibrated silicon cell IL.xlsx

Data: In spreadsheet – Data – highlighted in light purple

Appendix D

Table D.1 Type B uncertainties for TEM measurements.

Excel file: measurement uncertainty A and B.xlsx

Data: In spreadsheet – TEM, columns A - H – highlighted in light purple

Table D.2 Type B uncertainties in λ_{\max} for UV-vis and UV-vis-IR measurements.

Excel file: measurement uncertainty A and B.xlsx

Data: In spreadsheet – UV-vis and UV-vis-IR, columns A - H – highlighted in light pink

Table D.3 Type B uncertainties in Ab_{\max} for UV-vis and UV-vis-IR measurements.

Excel file: measurement uncertainty A and B.xlsx

Data: In spreadsheet – UV-vis and UV-vis-IR, columns J - Q – highlighted in light green

Table D.4 Type B uncertainty in calculating $\eta_{\text{lamp}(330 \text{ nm} - 1100 \text{ nm})}$.

Excel file: measurement uncertainty A and B.xlsx

Data: In spreadsheet – absorption eff from UV-vis-IR, columns A - H – highlighted in light orange

Table D.5 Type B uncertainty in calculating η_{PE} for the solar simulator set-up A.

Excel file: measurement uncertainty A and B.xlsx

Data: In spreadsheet –Solar simulator performance, columns A - H – highlighted in light blue

Table D.6 Type B uncertainty in calculating η_{PE} for the solar simulator set-up B.

Excel file: measurement uncertainty A and B.xlsx

Data: In spreadsheet –Solar simulator performance, columns J - Q – highlighted in light gold

Appendix E

Table E.1 Type A uncertainties for TEM measurements and expanded uncertainty U using a k value of 2.

Excel file: measurement uncertainty A and B.xlsx

Data: In spreadsheet –TEM, columns J - U – highlighted in light grey

Table E.2 Type A uncertainties for λ_{\max} and expanded uncertainty U using a k value of 2.

Excel file: measurement uncertainty A and B.xlsx

Data: In spreadsheet –UV-vis and UV-vis-IR, columns S - AD – highlighted in yellow

Table E.3 Type A uncertainties for Ab_{\max} and expanded uncertainty U using a k value of 2.

Excel file: measurement uncertainty A and B.xlsx

Data: In spreadsheet –UV-vis and UV-vis-IR, columns S – AD, rows 13 - 17 – highlighted in pink

Table E.4 Type A uncertainties for $\eta_{\text{lamp}(330 \text{ nm} - 1100 \text{ nm})}$ and expanded U using a k value of 2.

Excel file: measurement uncertainty A and B.xlsx

Data: In spreadsheet –absorption eff from UV-vis-IR, columns I – AQ – highlighted in green

Table E.5 Type A uncertainties for η_{PE} and expanded U using a k value of 2 for both solar simulator set-ups.

Excel file: measurement uncertainty A and B.xlsx

Data: In spreadsheet –solar simulator performance, columns S – AD – highlighted in blue

Appendix F

No additional data associated with this Appendix

Appendix G

Figure G.1 Graphic showing how the NPs were divided for the Ag NPs. Blue line = triangle, red line = rounded cornered triangle, pink line = other, green line = small and yellow line = thickness (undertaken on some samples see Section G.2). Thick red scale bar = 100 nm.

Power point: TEM eg of uncoated Ag measurements.pptx

Image file: Eg of uncoated TEM measurements.jpg

Table G.1 TEM analysis on Ag TSCD-PVP NPr 50 mL batch volume not centrifuged.

Excel file: TEM Ag NPrs TSCD PVP initial.xlsx

Data: In spreadsheet –Measurements – columns G – R – highlighted in light purple

Table G.2 TEM analysis on Ag TSCD-PVP NPr 50 mL batch volume not centrifuged – average results.

Excel file: TEM Ag NPrs TSCD PVP initial.xlsx

Data: In spreadsheet –Measurements – columns S – V – highlighted in light pink

Table G.3 TEM analysis on Ag TSCD-PVP NPr 50 mL batch volume after centrifuging and re-dispersal into $\frac{1}{4}$ volume water.

Excel file: TEM Ag NPrs TSCD PVP initial.xlsx

Data: In spreadsheet –Measurements – columns W – AH – highlighted in light gold

Table G.4 TEM analysis on Ag TSCD-PVP NPr centrifuged and re-dispersed into $\frac{1}{4}$ volume water – average results.

Excel file: TEM Ag NPrs TSCD PVP initial.xlsx

Data: In spreadsheet –Measurements – columns AI – AM – highlighted in light grey

Table G.5 TEM analysis on Ag TSCD-PVP NPr 25 mL batch size not centrifuged (long λ). The average λ_{\max} for 3 samples is also shown.

Excel file: TEM Ag NPrs TSCD PVP initial.xlsx

Data: In spreadsheet –Measurements – columns A – F – highlighted in yellow

Table G.6 Two-sample t-test results for TEM analysis of Ag TSCD-PVP NPr (where sample 2 is significantly smaller than sample 1 the average difference is shown as positive).

Excel file: TEM Ag NPrs TSCD PVP initial.xlsx

Data: In spreadsheet –Percentages – columns H – Q, rows 11 - 19 – highlighted in blue

Table G.7 TEM analysis on the broadband mixture and two of the component NFs. The average λ_{\max} for 3 samples is also shown.

Excel file: measurements broadband(TEM).xlsx

Data: In spreadsheet –percents – columns A – E, rows 28 - 37 – highlighted in purple

Table G.8 Two-sample t-test results for TEM analysis of the broadband mixture and its three component NFs (where sample 2 is significantly smaller than sample 1 the average difference is shown as positive). In all cases sample 1 is the broadband mixture.

Excel file: measurements broadband(TEM).xlsx

Data: In spreadsheet –percents – columns A – E, rows 39 - 51 – highlighted in light gold

Table G.9 TEM analysis on the broadband mixture and the component NFs produced using a 30 mL batch volume. The λ_{\max} for the combined samples is also shown.

Excel file: TEM consistency of batch.xlsx

Data: In spreadsheet –Data – columns A – U – highlighted in light pink

Table G.10 Two-sample t-test results for TEM analysis of the combined broadband mixture and its three component NFs compared to the 25 mL initial data in Table G.5 and Table G.7 (where sample 2 is significantly smaller than sample 1 the average difference is shown as positive).

Excel file: TEM consistency of batch.xlsx

Data: In spreadsheet –percents – columns A – U, rows 17 - 20 – highlighted in light gold

Table G.11 TEM analysis on the broadband mixture and the component NFs after 4 h exposure to a temperature of 70 °C. The average λ_{\max} after 4 h at 70 °C is also shown.

Excel file: TEM after temperature.xlsx

Data: In spreadsheet –Data – columns B – R – highlighted in light pink

Table G.12 Two-sample t-test results for TEM analysis of the broadband mixture and its three component NFs after exposure to a temperature of 70 °C compared to the initial data in Table G.9 (where sample 2 is significantly smaller than sample 1 the average difference is shown as positive).

Excel file: TEM after temperature.xlsx

Data: In spreadsheet –percents – columns A – H, rows 19 - 26 – highlighted in light purple

Table G.13 TEM analysis on Ag TSCD-PVP NPr 50 mL initial batch volume after centrifuging, re-dispersal into ¼ volume water and exposure to SSL for 12 h using set-up A.

Excel file: TEM after SSL.xlsx

Data: In spreadsheet –Ag NPrs set-up A – columns A – M – highlighted in light purple

Table G.14 TEM analysis on Ag TSCD-PVP NPr centrifuged, re-dispersed into ¼ volume water and exposure to SSL for 12 h using set-up A – average results.

Excel file: TEM after SSL.xlsx

Data: In spreadsheet –Ag NPrs set-up A – columns N – Q – highlighted in light pink

Table G.15 TEM analysis on the broadband mixture and the component NFs after 0.5 h exposure to SSL using set-up B. The average λ_{\max} after exposure is also shown.

Excel file: TEM after SSL.xlsx

Data: In spreadsheet –Broadband – columns A – U – highlighted in light gold

Table G.16 Two-sample t-test results for TEM analysis of the Ag TSCD-PVP NPr centrifuged and re-dispersed into ¼ volume water after exposure to SSL for 12 h using set-up A compared to the initial data in Table G.3 (where sample 2 is significantly smaller than sample 1 the average difference is shown as positive).

Excel file: TEM after SSL.xlsx

Data: In spreadsheet –percentages – columns A – I, rows 27 - 38 – highlighted in blue

Table G.17 Two-sample t-test results for TEM analysis of the broadband mixture and its three component NFs after exposure to SSL for 0.5 h using set-up B compared to the initial data in Table G.5 (long λ) and Table G.7 (where sample 2 is significantly smaller than sample 1 the average difference is shown as positive).

Excel file: TEM after SSL.xlsx

Data: In spreadsheet –percentages – columns J – P, rows 29 - 37 – highlighted in light grey

Table G.18 TEM analysis on the broadband absorber after exposure to flow, flow and elevated temperature, flow and SSL and flow, elevated temperature and SSL.

Excel file: TEM after flow.xlsx

Data: In spreadsheet –Data – columns F – U – highlighted in light pink

Table G.19 TEM analysis on Ag TSCD NPrs plus water-glass SiO₂, centrifuged and re-dispersed into ¼ volume of water BF, before and after exposure to SSL for 2 h using set-up A.

Excel file: TEM water glass SiO2.xlsx

Data: In spreadsheet –data – columns N – Q and AD - AG – highlighted in light pink

Table G.20 TEM analysis on Ag TSCD NPrs, with 5 x MPTMS plus water-glass SiO₂ in water BF or centrifuged and re-dispersed into ½ volume water / 50 % PG BF.

Excel file: TEM water glass SiO2.xlsx

Data: In spreadsheet –data – columns AH – AL and AY - BB – highlighted in light purple

Table G.21 Two-sample t-test results for TEM analysis of the water-glass SiO₂ NFs (where sample 2 is significantly smaller than sample 1 the average difference is shown as positive).

Excel file: TEM water glass SiO2.xlsx

Data: In spreadsheet – percents – columns A – R, rows 8 - 16 – highlighted in light gold

Table G.22 TEM analysis on Ag TSCD-PVP NPr before SiO₂ coating. The value of λ_{\max} is shown in brackets.

Excel file: TEM development of TEOS method.xlsx

Data: In spreadsheet –Data – columns A – F – highlighted in light pink

Figure G.2 Example of how the SiO₂ coated TEM measurements were undertaken. Light blue line = SiO₂ only NP, yellow line = single-cored SiO₂@Ag NP, red line = multi-cored SiO₂@Ag NP, green line = Ag inside, light orange line = Ag free (not SiO₂ coated), pink line = SiO₂ coating thickness. Thick red scale bar = 200 nm.

Power point: TEM eg of coated TEOS measurements.pptx

Image file: Eg of TEOS coated TEM measurement.jpg

Table G.23 TEM analysis on SiO₂@Ag NPr, 16 mM TEOS, 60 minutes, 20 µM MHA after SiO₂ coating to optimise the Stöber coating procedure. The λ_{\max} = 895 nm.

Excel file: TEM development of TEOS method.xlsx

Data: In spreadsheet –Data – columns G – L – highlighted in light purple

Table G.24 TEM analysis on SiO₂@Ag NPr, 10 mM TEOS, 60 minutes, 20 μM MHA after SiO₂ coating to optimise the Stöber coating procedure. The λ_{\max} = 873 nm.

Excel file: TEM development of TEOS method.xlsx

Data: In spreadsheet –Data – columns M – R – highlighted in light grey

Table G.25 TEM analysis on SiO₂@Ag NPr, 8 mM TEOS, 60 minutes, 20 μM MHA after SiO₂ coating to optimise the Stöber coating procedure. The λ_{\max} = 898 nm.

Excel file: TEM development of TEOS method.xlsx

Data: In spreadsheet –Data – columns S – X – highlighted in light gold

Table G.26 TEM analysis on SiO₂@Ag NPr, 1.6 mM TEOS, 60 minutes, 20 μM MHA after SiO₂ coating to optimise the Stöber coating procedure. The λ_{\max} = 897 nm.

Excel file: TEM development of TEOS method.xlsx

Data: In spreadsheet –Data – columns Y – AD – highlighted in blue

Table G.27 TEM analysis on SiO₂@Ag NPr, 10 mM TEOS, 30 minutes, 20 μM MHA after SiO₂ coating to optimise the Stöber coating procedure. The λ_{\max} = 898 nm.

Excel file: TEM development of TEOS method.xlsx

Data: In spreadsheet –Data – columns AE – AJ – highlighted in green

Table G.28 TEM analysis on SiO₂@Ag NPr, 10 mM TEOS, 30 minutes, 40 μM MHA after SiO₂ coating to optimise the Stöber coating procedure. The λ_{\max} = 876 nm.

Excel file: TEM development of TEOS method.xlsx

Data: In spreadsheet –Data – columns AK – AP – highlighted in yellow

Table G.29 TEM analysis on SiO₂@Ag NPr, 10 mM TEOS, 15 minutes, 40 μM MHA after SiO₂ coating to optimise the Stöber coating procedure. The λ_{\max} = 899 nm.

Excel file: TEM development of TEOS method.xlsx

Data: In spreadsheet –Data – columns AQ – AV – highlighted in light green

Table G.30 TEM analysis after SiO₂ coating using the optimised Stöber TEOS procedure (SiO₂@Ag NPr - 1, 10 mM TEOS, 30 minutes, 40 μM MHA). The λ_{\max} = 900 nm.

Excel file: Standard TEOS method TEM initial SiO2.xlsx

Data: In spreadsheet –Data – columns A – G – highlighted in light purple

Table G.31 TEM analysis after SiO₂ coating using the optimised Stöber TEOS procedure (SiO₂@Ag NPr - 2, 10 mM TEOS, 30 minutes, 40 μM MHA). The λ_{\max} = 836 nm.

Excel file: Standard TEOS method TEM initial SiO₂.xlsx

Data: In spreadsheet – Data – columns H – M – highlighted in light pink

Table G.32 TEM analysis after SiO₂ coating using the optimised Stöber TEOS procedure (SiO₂@Ag NPr - 3, 10 mM TEOS, 30 minutes, 40 μM MHA). The λ_{\max} = 836 nm.

Excel file: Standard TEOS method TEM initial SiO₂.xlsx

Data: In spreadsheet – Data – columns N – S – highlighted in light gold

Table G.33 TEM analysis after SiO₂ coating using the optimised Stöber TEOS procedure (SiO₂@Ag NPr - 4, 10 mM TEOS, 30 minutes, 40 μM MHA). The λ_{\max} = 817 nm.

Excel file: Standard TEOS method TEM initial SiO₂.xlsx

Data: In spreadsheet – Data – columns T – Y – highlighted in light orange

Table G.34 TEM analysis after SiO₂ coating using the optimised Stöber TEOS procedure (SiO₂@Ag NPr - 5, 10 mM TEOS, 30 minutes, 40 μM MHA). The λ_{\max} = 793 nm.

Excel file: Standard TEOS method TEM initial SiO₂.xlsx

Data: In spreadsheet – Data – columns Z – AE – highlighted in light grey

Table G.35 TEM analysis after SiO₂ coating using the optimised Stöber TEOS procedure (SiO₂@Ag NPr - 6, 10 mM TEOS, 30 minutes, 40 μM MHA). The λ_{\max} = 831 nm.

Excel file: Standard TEOS method TEM initial SiO₂.xlsx

Data: In spreadsheet – Data – columns AF – AK – highlighted in light green

Table G.36 TEM analysis after SiO₂ coating using the optimised Stöber TEOS procedure (SiO₂@Ag NPr - 7, 10 mM TEOS, 30 minutes, 40 μM MHA). The λ_{\max} = 898 nm.

Excel file: Standard TEOS method TEM initial SiO₂.xlsx

Data: In spreadsheet – Data – columns AL – AQ – highlighted in yellow

Table G.37 TEM analysis after SiO₂ coating using the optimised Stöber TEOS procedure (SiO₂@Ag NPr - 8, 10 mM TEOS, 30 minutes, 40 μM MHA). The λ_{\max} = 810 nm.

Excel file: Standard TEOS method TEM initial SiO₂.xlsx

Data: In spreadsheet – Data – columns AR – AW – highlighted in light blue

Table G.38 TEM analysis after SiO₂ coating using the optimised Stöber TEOS procedure (SiO₂@Ag NPr - 9, 10 mM TEOS, 30 minutes, 40 μM MHA). The λ_{\max} = 906 nm.

Excel file: Standard TEOS method TEM initial SiO₂.xlsx

Data: In spreadsheet – Data – columns AX – BC – highlighted in blue

Table G.39 TEM analysis after SiO₂ coating using the optimised Stöber TEOS procedure (SiO₂@Ag NPR - 11, 10 mM TEOS, 30 minutes, 40 μM MHA). The λ_{\max} = 876 nm.

Excel file: Standard TEOS method TEM initial SiO2.xlsx

Data: In spreadsheet – Data – columns BD – BI – highlighted in green

Figure G.3 Boxplots showing the TEM SiO₂ coating thickness results (the results obtained in Table G.28 is shown for comparison). All produced using 10 mM TEOS, 40 μM MHA for 30 minutes.

Excel file: Standard TEOS method TEM initial SiO2.xlsx

Data: In spreadsheet –ANOVA results – highlighted in green

Graph: SiO2 TEOS coating thickness.MPJ (Minitab file) – Boxplot of SiO₂@Ag NPR,, SiO₂@Ag NPR,,

Original data: SiO2 TEOS coating thickness.MPJ

Power point: SiO2 TEOS coating thickness.pptx

Image file: SiO2 TEOS coating thickness.jpg

Table G.40 ANOVA results for the thickness of the SiO₂ coating in descending order of thickness.

Both SiO₂@Ag NPR – 7 and SiO₂@Ag NPR development where produced using a smaller batch volume.

Excel file: Standard TEOS method TEM initial SiO2.xlsx

Data: In spreadsheet – ANOVA results – highlighted in green

Table G.41 TEM analysis after storage in at 4 °C in the dark for 51 days for SiO₂@Ag NPR - 1 re-dispersed into ¼ volume of water. The λ_{\max} = 804 nm.

Excel file: SiO2 standard colloidal stability.xlsx

Data: In spreadsheet – TEM after – columns A – G - highlighted in green

Table G.42 TEM analysis after storage in at 4 °C in the dark for 49 days for SiO₂@Ag NPR - 2 re-dispersed into ¼ volume of water. The starting λ_{\max} = 726 nm.

Excel file: SiO2 standard colloidal stability.xlsx

Data: In spreadsheet – TEM after – columns H – M - highlighted in blue

Table G.43 TEM analysis after storage in at 4 °C in the dark for 49 days for SiO₂@Ag NPR - 3 re-dispersed into ¼ volume of water. The starting λ_{\max} = 803 nm.

Excel file: SiO2 standard colloidal stability.xlsx

Data: In spreadsheet – TEM after – columns N – S - highlighted in light grey

Table G.44 Two-sample un-paired t-test results for TEM analysis of SiO₂@Ag NPrs before and after storage in the dark at 4 °C for ≈ 50 days (where sample 2 is significantly smaller than sample 1 the average difference is shown as positive).

Excel file: SiO₂ standard colloidal stability.xlsx

Data: In spreadsheet – TEM after – columns AA – AE - highlighted in light purple

Table G.45 TEM analysis after exposure to 70 °C for 18 h for SiO₂@Ag NPr - 8 re-dispersed into the same volume of water as the initial uncoated NF. Note that there were signs of porosity in the SiO₂ coating on the TEM micrographs.

Excel file: SiO₂ standard temperature stability.xlsx

Data: In spreadsheet – TEM after – columns A – F - highlighted in light purple

Table G.46 TEM analysis after exposure to 70 °C for 18 h for SiO₂@Ag NPr - 10 diluted to give an $Ab_{\max} \approx 0.8$ au (for a 10 mm path length cuvette) prior to temperature exposure. Note that there were signs of porosity in the SiO₂ coating on the TEM micrographs.

Excel file: SiO₂ standard temperature stability.xlsx

Data: In spreadsheet – TEM after – columns L – Q - highlighted in light gold

Table G.47 TEM analysis after exposure to 70 °C for 18 h for SiO₂@Ag NPr - 12 diluted to give an $Ab_{\max} \approx 0.8$ au (for a 10 mm path length cuvette) prior to temperature exposure. Note that the majority of Ag NPs were no longer coated with SiO₂ and there were significant signs of porosity in the SiO₂ coating on the TEM micrographs.

Excel file: SiO₂ standard temperature stability.xlsx

Data: In spreadsheet – TEM after – columns R – Z - highlighted in light pink

Table G.48 TEM analysis after exposure to 70 °C for 18 h for SiO₂@Ag NPr - 8 re-dispersed into ¼ volume of water (compared to the original NF). Note that only one Ag NP was still coated with SiO₂ and there were no triangular or rounded cornered triangular free Ag NPs present on the TEM micrographs.

Excel file: SiO₂ standard temperature stability.xlsx

Data: In spreadsheet – TEM after – columns G – K - highlighted in light grey

Table G.49 TEM analysis before exposure to SSL for 6 h for SiO₂@Ag NPr re-dispersed into ¼ volume of water (compared to the initial uncoated NF) – Average results from Table G.30, Table G.31, and Table G.32 ($N = 3$).

Excel file: SiO₂ standard SSL stability.xlsx

Data: In spreadsheet – TEM after – columns U – Z - highlighted in light grey

Table G.50 TEM analysis after exposure to SSL for 6 h for SiO₂@Ag NPR - 1 re-dispersed into ¼ volume of water (compared to the initial uncoated NF).

Excel file: SiO2 standard SSL stability.xlsx

Data: In spreadsheet – TEM after – columns A – G, row 12 onwards - highlighted in green

Table G.51 TEM analysis after exposure to SSL for 6 h for SiO₂@Ag NPR - 2 re-dispersed into ¼ volume of water (compared to the initial uncoated NF).

Excel file: SiO2 standard SSL stability.xlsx

Data: In spreadsheet – TEM after – columns H – M, row 12 onwards - highlighted in blue

Table G.52 TEM analysis after exposure to SSL for 6 h for SiO₂@Ag NPR - 3 re-dispersed into ¼ volume of water (compared to the initial uncoated NF).

Excel file: SiO2 standard SSL stability.xlsx

Data: In spreadsheet – TEM after – columns N – S, row 12 onwards - highlighted in light pink

Table G.53 Two-sample un-paired t-test results for TEM analysis of SiO₂@Ag NPRs before and after exposure to SSL for 6 h (where sample 2 is significantly smaller than sample 1 the average difference is shown as positive).

Excel file: SiO2 standard SSL stability.xlsx

Data: In spreadsheet – TEM after – columns AG – AK - highlighted in orange

Table G.54 TEM analysis after SiO₂ coating using the optimised Stöber procedure and an extra initial purification step (SiO₂@Ag NPR – extra initial purification – average, $N = 2$).

Excel file: modifications to SiO2.xlsx

Data: In spreadsheet – extra wash TEM – columns H – M, row 11 onwards - highlighted in orange

Table G.55 TEM analysis after SiO₂ coating using the optimised Stöber procedure and an extra final purification step (SiO₂@Ag NPR – extra final purification step – average, $N = 3$).

Excel file: modifications to SiO2.xlsx

Data: In spreadsheet – extra wash TEM – columns N – S, row 11 onwards - highlighted in green

Table G.56 Two-sample un-paired t-test results for TEM analysis of SiO₂@Ag NPRs (optimised Stöber process, no extra purification – Table 6.2) and SiO₂@Ag NPRs produced using an initial extra purification step (where sample 2 is significantly smaller than sample 1 the average difference is shown as positive).

Excel file: modifications to SiO2.xlsx

Data: In spreadsheet – extra wash TEM – as highlighted in blue

Table G.57 Two-sample un-paired t-test results for TEM analysis of SiO₂@Ag NPrs (optimised Stöber process, no extra purification – Table 6-2) and SiO₂@Ag NPrs produced using a final extra purification step (where sample 2 is significantly smaller than sample 1 the average difference is shown as positive).

Excel file: modifications to SiO2.xlsx

Data: In spreadsheet – extra wash TEM – as highlighted in light gold

Table G.58 TEM analysis after SiO₂ coating using no MHA and ¼ concentration of DMA (SiO₂@Ag NPrs, 0 MHA, ¼ concentration DMA).

Excel file: modifications to SiO2.xlsx

Data: In spreadsheet – MHA DMA TEM – columns BP – BU, row 16 onwards highlighted in light pink

Table G.59 TEM analysis after SiO₂ coating using 160 µM MHA and an additional purification step at the end of the process. Average results from 3 separate samples.

Excel file: modifications to SiO2.xlsx

Data: In spreadsheet – MHA DMA TEM – columns B – G, row 16 onwards highlighted in light purple

Table G.60 TEM analysis after SiO₂ coating using 40 µM MHA and ¼ volume of DMA.

Excel file: modifications to SiO2.xlsx

Data: In spreadsheet – MHA DMA TEM – columns AR – AW, row 16 onwards highlighted in light grey

Table G.61 TEM analysis after SiO₂ coating using 160 µM MHA and ¼ volume of DMA.

Excel file: modifications to SiO2.xlsx

Data: In spreadsheet – MHA DMA TEM – columns BD – BI, row 16 onwards highlighted in green

Table G.62 TEM analysis after SiO₂ coating using a TEOS reaction time of 1 minute, as synthesised.

Excel file: modifications to SiO2.xlsx

Data: In spreadsheet – TEOS time TEM – columns B – G, row 16 onwards highlighted in light pink

Table G.63 TEM analysis after SiO₂ coating using a TEOS reaction time of 5 minutes, as synthesised.

Excel file: modifications to SiO2.xlsx

Data: In spreadsheet – TEOS time TEM – columns H – M, row 16 onwards highlighted in light purple

Table G.64 ANOVA results for the thickness of the SiO₂ coating in descending order of thickness, for samples produced using different TEOS reaction times. The 30 minute reaction time values are from Table 6-2. Groups that do not share a letter are significantly different.

Excel file: modifications to SiO₂.xlsx

Data: In spreadsheet – TEOS time TEM – columns AL – AU - highlighted in light grey

Table G.65 TEM analysis after SiO₂ coating using a TEOS reaction time of 1 minute or 5 minutes, after 18 h at 70 °C.

Excel file: modifications to SiO₂.xlsx

Data: In spreadsheet – TEOS time TEM – columns AD – AK - highlighted in orange

Figure G.4 Summary of TEM analysis after 18 h at 70 °C for the SiO₂@Ag NPRs produced using a TEOS reaction time of 1 minute and 5 minutes (also shown is the results for Ag TSCD-PVP NPRs (long λ) after 4 h at 70 °C from Figure 5-5 for comparison).

Excel file: modifications to SiO₂.xlsx

Spreadsheet: percents grph

Data: In spreadsheet – TEOS time TEM – columns AV – AY - highlighted in green

Table G.66 TEM analysis after SiO₂ coating for the SiO₂@broadband NF.

Excel file: SiO₂ coated broadband.xlsx

Data: In spreadsheet – TEM – columns A – G - highlighted in orange

Table G.67 Two-sample un-paired t-test results for TEM analysis of SiO₂@broadband NF compared to SiO₂@Ag NPRs produced using the developed Stöber TEOS method (Table 6-2). Where sample 2 is significantly smaller than sample 1 the average difference is shown as positive.

Excel file: SiO₂ coated broadband.xlsx

Data: In spreadsheet – TEM – columns J – Q - highlighted in light pink

Appendix H

Table H.1 Details of experiments investigating effect of overall concentration.

Excel file: Effect of Ag concentration for Ag NPR.xlsx

Data: In spreadsheet – data – columns E – N - highlighted in light pink

Figure H.1 UV-vis spectra showing the effect of overall reagent concentration on the resultant NPs.

All measured with a 10 mm path length cuvette on UV-vis-1. Samples with a starting Ag concentration > 0.1 mM have been diluted prior to measurement.

Excel file: Effect of Ag concentration for Ag NPR.xlsx

Spreadsheet: silver conc grph

Data: In spreadsheet – data – columns A – E - highlighted in light purple

Table H.2 Experiments investigating changing the amount of H₂O₂ – Batch size 25 mL.

Excel file: Effect of H₂O₂ amount on Ag NP.xlsx

Data: In spreadsheet – Data – columns F – K - highlighted in light pink

Figure H.2 Effect of varying the amount of H₂O₂ on the UV-vis spectra. All samples measured using a 10 mm path length cuvette and UV-vis-1.

Excel file: Effect of Ag concentration for Ag NPr.xlsx

Spreadsheet: H₂O₂ grph

Data: In spreadsheet – data – columns A – G, row 12 onwards - highlighted in light purple

Table H.3 Details of experiments undertaken to investigate the effect of Ag: NaBH₄ ratio. Batch size = 25 mL.

Excel file: Effect of Ag to NaBH₄ ratio on Ag NPrs.xlsx

Data: In spreadsheet – Data – columns H – P - highlighted in light pink

Figure H.3 Effect of a 1: 5 Ag: NaBH₄ ratio at different overall starting concentrations of Ag. All samples using an Ag: NaBH₄ ratio of 1: 5 and the same relative amount of H₂O₂ as the TSCD-PVP NPr recipe in Section 3.5.3. All measured on the UV-vis-1 spectrophotometer using a 10 mm path length 3 mL disposable cuvette. Samples with a starting Ag concentration of > 0.1 mM have been diluted.

Excel file: Effect of Ag to NaBH₄ ratio on Ag NPrs.xlsx

Spreadsheet: NaBH₄ grph

Data: In spreadsheet – data – columns A – E, row 13 onwards - highlighted in light purple

Figure H.4 UV-vis spectra showing the effect of varying the Ag: NaBH₄ ratio and the amount of H₂O₂ using a starting Ag concentration of 0.3 mM Ag. All measured using UV-vis-1 and a 10 mm path length 3 mL disposable cuvette. All samples diluted in the ratio 1: 3.

Excel file: Effect of Ag to NaBH₄ ratio on Ag NPrs.xlsx

Spreadsheet: NaBH₄ and H₂O₂ changes grph

Data: In spreadsheet – data – columns F – K, row 14 onwards - highlighted in light grey

Table H.4 Details of samples investigating the timing of NaBH₄ addition, starting with seed = 0.3 mM Ag TSCD-PVP NP, 1: 5, 100 % H₂O₂ (mid λ). All samples have been diluted 1: 3 prior to UV-vis measurement using a 10 mm, 1 mL disposable cuvette on UV-vis-1.

Excel file: Timing of NaBH₄ effect on Ag NPr.xlsx

Data: In spreadsheet – Data – columns G - N - highlighted in light purple and in spreadsheet – Ratios – columns A – M – highlighted in light pink

Figure H.5 Effect of adding NaBH₄ to an already synthesised seed NF. Seed = 0.3 mM Ag TSCD-PVP NP, 1: 5 Ag: NaBH₄, 100 % H₂O₂. Each aliquot of NaBH₄ is 0.01 mL of 25 mM solution into an original starting volume of 2 mL. Samples were diluted 1: 3 and measured using a 10 mm path length 1 mL micro cuvette using UV-vis-1.

Excel file: Timing of NaBH₄ effect on Ag NPr.xlsx

Spreadsheet: NaBH₄ timing grph

Data: In spreadsheet – For thesis – columns A – L - highlighted in light gold

Figure H.6 The relationship between the total amount of NaBH₄ (relative to Ag amount), λ_{\max} and Ab_{\max} for a starting seed of 0.3 mM Ag TSCD-PVP NP, 1: 5, 100 % H₂O₂ (mid λ).

Excel file: Timing of NaBH₄ effect on Ag NPr.xlsx

Spreadsheet: ratio thesis seed grph

Data: In spreadsheet – Ratios – rows 10 – 21 - highlighted in light grey

Table H.5 Details of samples investigating adding NaBH₄ to four other seed solutions. Samples using Seeds W and X have been diluted 1: 3 prior to measurement and samples using Seeds Y and Z have been diluted 1: 4. All measured with a 1 mL 10 mm path length cuvette using UV-vis-1.

Excel file: Timing of NaBH₄ effect on Ag NPr.xlsx

Data: In spreadsheet – For appendix – columns A – O, rows 2 - 7 - highlighted in light blue and in spreadsheet – Data – columns G – N – highlighted in blue

Figure H.7 UV-vis spectra investigating the addition of NaBH₄ to an already synthesised seed solution starting with Seeds W, X and Y (see Table H.5 for seed details). All measured using a 10 mm path length 1 mL micro cuvette with UV-vis-1. All samples diluted in ratio 1: 3 (Seeds W and X) and 1: 4 (Seed Y).

Excel file: Timing of NaBH₄ effect on Ag NPr.xlsx

Spreadsheet: 1st appendix grph

Data: In spreadsheet – For appendix – columns A -H - highlighted in pink

Figure H.8 UV-vis spectra showing the effect of adding successive aliquots of NaBH₄ to an already synthesised seed solution (Seed Z in Table H.5). All samples diluted in ratio 1: 4 and measured with a 1 mL, 10 mm path length cuvette on UV-vis-1.

Excel file: Timing of NaBH₄ effect on Ag NPr.xlsx

Spreadsheet: 2st appendix grph

Data: In spreadsheet – For appendix – columns J -O - highlighted in orange

Table H.6 Details of samples produced to investigate the addition of both Ag and NaBH₄ to an already produced seed NF. Seed = 0.3 mM Ag TSCD-PVP NP, 1: 5 Ag: NaBH₄, 50 % H₂O₂. Note that the seed alone sample was diluted 1: 3 for UV-vis and all other samples were diluted 1: 5.

Excel file: Adding Ag and NaBH₄ after for Ag NP.xlsx

Data: In spreadsheet – Data – as highlighted in light pink

Figure H.9 UV-vis-1 spectra showing the effect of adding both AgNO₃ and NaBH₄ to an already prepared seed solution. All measured on UV-vis-1 using a 10 mm 3 mL disposable cuvette. The seed solution was diluted 1: 3 and all other solution were diluted 1: 5 prior to UV-vis measurement (details of seed solution in Table H.6).

Excel file: Adding Ag and NaBH₄ after for Ag NP.xlsx

Spreadsheet: Ag and NaNH₄ grph

Data: In spreadsheet – Data – columns A -F - highlighted in light purple

Table H.7 Various different efficiency calculations for the three component NFs selected for the broadband absorber. The long λ NF was not diluted prior to UV-vis measurement.

Excel file: AE calculations broadband.xlsx

Data: In spreadsheet – absorbance – sample names in columns AL – DD, row 7, results – columns AL – DD, rows 1059 – 1062 and 1064 - highlighted in pink

Table H.8 Calculations of optimum broadband mixture. The recipe in bold was chosen as although not the optimum in terms of $\eta_{Ab(300\text{ nm} - 1350\text{ nm})}$ it contained a lower proportion of the mid λ NF and still a $\eta_{Ab(300\text{ nm} - 1350\text{ nm})} > 82\%$.

Excel file: Optimisation of Mixture.xlsx

Data: In spreadsheet – Summary – columns A – P, rows 13 – 18 and 20, 21 - highlighted in light pink

Table H.9 Effect of changing the short λ recipe on $\eta_{Ab(300\text{ nm} - 1350\text{ nm})}$ for a mixture containing 30 % short λ , 20 % mid λ and 50 % long λ .

Excel file: Optimisation of Mixture.xlsx

Data: In spreadsheet – Summary – columns Q and R, rows 13 – 18 and 20, 21 - highlighted in light purple

Table H.10 Calculations of optimum broadband mixture showing various different efficiency metrics.

The row in bold is the selected mixture.

Excel file: Optimisation of Mixture.xlsx

Data: In spreadsheet – Summary – columns A - P, rows 19 and 22 - 24 - highlighted in orange

Table H.11 Various efficiency values for the measured and calculated broadband absorber.

Excel file: AE calculations broadband.xlsx

Data: In spreadsheet – absorbance – sample names in columns H – AG, row 7, results – columns H – AG, rows 1060 – 1062 and 1064 - highlighted in purple

Also $\eta_{lamp(330 - 1100\text{ nm})} / \%$ in Excel file: Lamp vs G173 solar broadband AE lamp cal.xlsx

Data: In spreadsheet – AE lamp spec – sample names in columns FS - FX, row 2, results – columns FS - FX, row 2407 - highlighted in green

Appendix I

Figure I.1 UV-vis spectra for the short λ NF 30 mL samples. The error bars show the range of results obtained at the maximum absorbance for the repeat synthesis. The 30 mL batch samples were measured using UV-vis-1 and a 1 mL 10 mm path length disposable cuvette. The combined sample was measured using UV-vis-IR-1 and a 3 mL 10 mm path length cuvette. The samples have been diluted 1: 5. For ease of comparison the short λ NF from Figure 4-10 is also shown.

Excel file: UV-vis flow and consistency of batch.xlsx

Spreadsheet: short initial grph

Data: In spreadsheet – for graphs - columns A -F - highlighted in pink

Table I.1 λ_{max} and Ab_{max} values for the repeat synthesis of the short λ NF with a batch size of 30 mL.

All initial samples measured on UV-vis-1 using a 10 mm path length, 1 mL micro cuvette. The combined sample was measured on UV-vis-IR-1 using a 3 mL 10 mm path length disposable cuvette.

Excel file: UV-vis flow and consistency of batch.xlsx

Data: In spreadsheet – flow normalised – columns AG – AR and BZ, rows 5 - 18 - highlighted in green

Figure I.2 UV-vis spectra for the mid λ NF 30 mL samples. The error bars show the range of results obtained at the maximum absorbance for the repeat synthesis. The 30 mL batch samples were initially measured using UV-vis-1 and a 1 mL 10 mm path length disposable cuvette. They were then re-measured after 2 weeks using UV-vis-IR-1. The

combined sample was measured on UV-vis-1 just after diluting and then on UV-vis-IR-1 using a 3 mL 10 mm path length cuvette. For ease of comparison the mid λ NF from Figure 4-10 is also shown.

Excel file: UV-vis flow and consistency of batch.xlsx

Spreadsheet: Mid initial grph

Data: In spreadsheet – for graphs - columns G -P - highlighted in blue

Table I.2 λ_{\max} and Ab_{\max} values for the repeat synthesis of the mid λ NF with a batch size of 30 mL. All measured on UV-vis-1 using a 10 mm path length, 1 mL micro cuvette. Note that samples were diluted to 0.3 mL in 1 mL rather than 0.33 mL in 1 mL hence Ab_{\max} has been adjusted to allow comparison with the 25 mL mid λ batch samples.

Excel file: UV-vis flow and consistency of batch.xlsx

Data: In spreadsheet – flow normalised – columns X – AE, rows 1 - 18 - highlighted in light gold

Table I.3 λ_{\max} and Ab_{\max} values for the repeat synthesis of the mid λ NF with a batch size of 30 mL 2 weeks after manufacture. All initial samples measured on UV-vis-IR-1 using a 10 mm path length, 1 mL micro cuvette. Note that samples were diluted to 0.3 mL in 1 mL rather than 0.33 mL in 1 mL hence Ab_{\max} has been adjusted to allow comparison with the 25 mL mid λ and batch samples. The combined mid λ sample was diluted 1: 3 and measured using a 3 mL 10 mm path length cuvette.

Excel file: UV-vis flow and consistency of batch.xlsx

Data: In spreadsheet – flow normalised – columns BO – BV, BY, and CF rows 1 - 18 - highlighted in light green

Table I.4 Results of undertaking ANOVA on the mid λ , λ_{\max} values. The average values and the potential range of the average value are shown along with the grouping. Groups that do not share a letter are significantly different.

Excel file: UV-vis flow and consistency of batch.xlsx

Data: In spreadsheet – Transposed for minitab – columns AB - AH - highlighted in light pink

Table I.5 Results of undertaking ANOVA on the mid λ , Ab_{\max} values. The average values and the potential range of the average value are shown along with the grouping. Groups that do not share a letter are significantly different.

Excel file: UV-vis flow and consistency of batch.xlsx

Data: In spreadsheet – Transposed for minitab – columns V - AA - highlighted in light grey

Figure I.3 UV-vis spectra for the long λ NF 30 mL samples. The error bars show the range of results obtained at the maximum absorbance for the repeat synthesis ($N = 20$). Measured using a 1 mL 10 mm path length cuvette on UV-vis-IR-1. For ease of comparison the long λ NFs from Figure 4-10 and Figure 4-5 is also shown.

Excel file: UV-vis flow and consistency of batch.xlsx

Spreadsheet: long initial grph

Data: In spreadsheet – for graphs - columns Q -X - highlighted in orange

Table I.6 λ_{\max} and Ab_{\max} values for the repeat synthesis of the long λ NF with a batch size of 30 mL. All measured on UV-vis-IR-1 using a 10 mm path length, 1 mL micro cuvette.

Excel file: UV-vis flow and consistency of batch.xlsx

Data: In spreadsheet – flow normalised – columns AT – BM and BX - highlighted in blue

Table I.7 Results of undertaking ANOVA on the long λ , λ_{\max} values. The average values and the potential range of the average value are shown along with the grouping. Groups that do not share a letter are significantly different.

Excel file: UV-vis flow and consistency of batch.xlsx

Data: In spreadsheet – Transposed for minitab – columns P - U - highlighted in yellow

Table I.8 Results of undertaking ANOVA on the long λ , Ab_{\max} values. The average values and the potential range of the average value are shown along with the grouping. Groups that do not share a letter are significantly different.

Excel file: UV-vis flow and consistency of batch.xlsx

Data: In spreadsheet – Transposed for minitab – columns J - O - highlighted in purple

Appendix J

Figure J.1 Spectra obtained from the solar simulator lamp and from sunlight. The sunlight spectrum was measured at 12 noon on a sunny day. Both measured using UV-vis-IR-2 in count mode (only the Avaspec -2048 spectrophotometer and not the Hal-lamp).

Excel file: lamp versus sunlight.xlsx

Spreadsheet: Spectra grph

Data: In spreadsheet – Sheet 1 – columns A, BS and CS - highlighted in yellow

Table J.1 Solar simulator results for repeat measurements on the base-fluid water for set-up A. The confidence level shows the range of possible values for the mean. The grouping shows results that are significantly different.

Excel file: Ag Npr ct SSL response surface vs water.xlsx

Data: In spreadsheet – Water – columns A - O - highlighted in orange

Table J.2 Solar simulator results for repeat measurements of water using Set-up B including the calculation of η_{PE} using the parameters given in Table 3-3 and Equation 3-10.

Excel file: summarised PE data broadband absorber.xlsx

Data: In spreadsheet – PE % – columns L - O and column AC – AF, row 47 - highlighted in light pink

Table J.3 Experimental design for response surface methodology.

Excel file: Ag Npr ct SSL response surface vs water.xlsx

Data: In spreadsheet – minitab 9 hr worksheet - highlighted in light green

Figure J.2 Main Effect Plots for (A) Value of ΔT after 3600 s in SSL, and (B) The slope $\Delta T/\Delta t$ taken between $t = 90$ s to $t = 150$ s. Ag NPR ct $\frac{1}{4}$ vol are Ag TSCD-PVP NPRs centrifuged and re-dispersed into $\frac{1}{4}$ volume of water. Position refers to placement in SSL apparatus where B = Back, F = front and Md = Middle.

Power point: Main effect for Ag NPR in SSL.pptx – slide 2

Image file:Main effects for Ag NPRs in SSL.jpg

Related excel file: Ag Npr ct SSL response surface vs water.xlsx

Data: In spreadsheet – response surface – columns Q –Y – highlighted in light purple

Table J.4 Solar simulator results for repeat measurements on Ag NPR ct $\frac{1}{4}$ vol NF for Set-up A. The confidence level shows the range of possible values for the mean. The grouping shows results that are significantly different.

Excel file: SSL Ag NPR and SiO2 Ag NPR temperature data.xlsx

Data: In spreadsheet – Mean sum delta T – columns AD - AP - highlighted in light pink

Table J.5 Calculations of η_{PE} (using set-up A) and $\eta_{lamp(330\text{ nm} - 900\text{ nm})}$ for water and Ag TSCD-PVP NPR centrifuged and re-dispersed into $\frac{1}{4}$ volume of water.

η_{PE} in Excel file: SSL Ag NPR and SiO2 Ag NPR temperature data.xlsx

η_{PE} Data: In spreadsheet – Delta T – columns B, C, K, L rows 9 – 12 - highlighted in orange

$\eta_{\text{lamp}(330 \text{ nm} - 900 \text{ nm})}$ in Excel file: Lamp vs G173 solar broadband AE lamp cal.xlsx

$\eta_{\text{lamp}(330 \text{ nm} - 900 \text{ nm})}$ Data: In spreadsheet – AE lamp spec - columns HL and HR, rows 2410 – 2412 – highlighted in light grey

Table J.6 Experimental design for response surface methodology for the SiO₂ containing NFs and water.

Excel file: Ag Npr ct SSL response surface vs water.xlsx

Data: In spreadsheet – minitab 6 hrs SiO₂ – highlighted in green

Table J.7 Solar simulator results for repeat measurements on SiO₂ only NF for Set-up A. The confidence level shows the range of possible values for the mean. The grouping shows results that are significantly different.

Excel file: SSL Ag NPr and SiO₂ Ag NPr temperature data.xlsx

Data: In spreadsheet – Mean sum delta T – columns AR – AX highlighted in light grey

Figure J.3 Main Effect Plots for (A) Value of ΔT after 3600 s in SSL, and (B) The slope $\Delta T/\Delta t$ taken between $t = 90$ s to $t = 150$ s for SiO₂, SiO₂@Ag NPrs centrifuged and re-dispersed into $\frac{1}{4}$ volume of water, and water. Position refers to placement in SSL apparatus where B = Back, F = front and Md = Middle.

Power point: Main effect for Ag NPr in SSL.pptx – slide 3

Image file:Main effects for SiO₂ SiO₂ Ag NPr in SSL.jpg

Related excel file: Ag Npr ct SSL response surface vs water.xlsx

Data: In spreadsheet – response surface – columns AA –AH – highlighted in blue

Table J.8 Solar simulator results for repeat measurements on SiO₂@Ag NPr NF for Set-up A. The confidence level shows the range of possible values for the mean. The grouping shows results that are significantly different.

Excel file: SSL Ag NPr and SiO₂ Ag NPr temperature data.xlsx

Data: In spreadsheet – Mean sum delta T – columns AZ – BF highlighted in orange

Table J.9 Calculations of η_{PE} (using set-up A) for SiO₂ NF and SiO₂@Ag NPr and $\eta_{\text{lamp}(330 \text{ nm} - 900 \text{ nm})}$ for SiO₂@Ag NPr re-dispersed into $\frac{1}{4}$ volume of water.

η_{PE} in Excel file: SSL Ag NPr and SiO₂ Ag NPr temperature data.xlsx

η_{PE} Data: In spreadsheet – Delta T – columns BS, BT,DO,DP rows 9 – 12 - highlighted in light grey

$\eta_{\text{lamp}(330 \text{ nm} - 900 \text{ nm})}$ in Excel file: Lamp vs G173 solar broadband AE lamp cal.xlsx

$\eta_{\text{lamp}(330 \text{ nm} - 900 \text{ nm})}$ Data: In spreadsheet – AE lamp spec - columns HO and HU, rows 2410 – 2412 – highlighted in purple

Appendix K

Table K.1 Studies that have investigated the effect of time (i.e. colloidal stability), temperature or light on silver NF.

No additional data associated with this Table

Figure K.1 Change in Ab_{max} for a number of different NF after storage in the dark at 4 °C. The short λ NF was diluted 1: 5 prior to storage, the 25 mL batch size mid λ NF was diluted 1: 3, whereas the 30 mL batch size mid λ NF was diluted 0.3 mL in 1 mL.

Excel file: colloid stability.xlsx

Spreadsheet: Abmax grph all

Data: In spreadsheet – All - columns B – I, rows 6 - 114 - highlighted in light pink

Figure K.2 Change in λ_{max} with storage in the dark at 4 °C for various different NFs. Both the short λ and mid λ NFs have been diluted prior to storage.

Excel file: colloid stability.xlsx

Spreadsheet: pos grph all

Data: In spreadsheet – All - columns B – I, rows 116 - 224 - highlighted in light purple

Figure K.3 UV-vis spectra of the broadband absorber (batch 1) initially and after storage in the dark at 4 °C for a maximum of 603 days. The sample was measured using UV-vis-IR-1 initially and at $t = 23$ days and using UV-vis-IR-2 after 335 days and 603 days.

Excel file: colloid stability.xlsx

Spreadsheet: broad 1 grph

Data: In spreadsheet – broadband - columns F – J, starting at row 12 - highlighted in orange

Figure K.4 UV-vis spectra of the broadband absorber (batch 2) initially and after storage in the dark at 4 °C for a maximum of 603 days. The sample was measured using UV-vis-IR-1 initially and at $t = 23$ days and using UV-vis-IR-2 after 335 days and 603 days.

Excel file: colloid stability.xlsx

Spreadsheet: broad 2 grph

Data: In spreadsheet – broadband - columns K – O, starting at row 12 - highlighted in light gold

Figure K.5 UV-vis spectra of the broadband absorber (batch 3) initially and after storage in the dark at 4 °C for a maximum of 335 days. The sample was measured using UV-vis-IR-1 initially and at $t = 23$ days and using UV-vis-IR-2 after 335 days.

Excel file: colloid stability.xlsx

Spreadsheet: broad 3 grph

Data: In spreadsheet – broadband - columns P – S, starting at row 12 - highlighted in light purple

Figure K.6 UV-vis spectra of the broadband absorber (batch 4) initially and after storage in the dark at 4 °C for a maximum of 511 days. The sample was measured using UV-vis-IR-1 initially and using UV-vis-IR-2 after 246 days and 511 days.

Excel file: colloid stability.xlsx

Spreadsheet: broad 4 grph

Data: In spreadsheet – broadband - columns T – W, starting at row 12 - highlighted in light grey

Figure K.7 UV-vis spectra of the broadband absorber (batch 5) initially and after storage in the dark at 4 °C for a maximum of 236 days.

Excel file: colloid stability.xlsx

Spreadsheet: broad 5 grph

Data: In spreadsheet – broadband - columns X – AI, starting at row 12 - highlighted in yellow

Figure K.8 UV-vis spectra of the broadband absorber (batch 6) initially and after storage in the dark at 4 °C for a maximum of 236 days.

Excel file: colloid stability.xlsx

Spreadsheet: broad 6 grph

Data: In spreadsheet – broadband - columns AJ – AU, starting at row 12 - highlighted in green

Figure K.9 UV-vis spectra of the broadband absorber (batch 7) initially and after storage in the dark at 4 °C for a maximum of 236 days.

Excel file: colloid stability.xlsx

Spreadsheet: broad 7 grph

Data: In spreadsheet – broadband - columns AV – BB, starting at row 12 - highlighted in blue

Figure K.10 Change in λ_{\max} with exposure to a temperature of 70 °C for Ag NS and the short λ NF (the short λ NF has been diluted 1: 5 prior to testing). The average starting λ_{\max} is shown in brackets ($N = 3$ in all cases).

Excel file: Temperature stability uncoated.xlsx

Spreadsheet: All position grph

Data: In spreadsheet – All - columns B – E, starting at row 7 - highlighted in light pink

Figure K.11 Change in Ab_{max} with exposure to a temperature of 70 °C for Ag NS and the short λ NF (the short λ NF has been diluted 1: 5 prior to testing).

Excel file: Temperature stability uncoated.xlsx

Spreadsheet: All Abmax grph

Data: In spreadsheet – All - columns O – R, starting at row 7 - highlighted in light purple

Table K.2 Two-sample t-test results for Ag NS and short λ NF before and after exposure to elevated temperature (only the significant differences shown).

Excel file: Temperature stability uncoated.xlsx

Data: In spreadsheet – NS – as highlighted in green and in spreadsheet – short – as highlighted in blue

Figure K.12 Change in λ_{max} with exposure to a temperature of 70 °C for the mid λ NF and various different Ag NPr NFs (the mid λ NF has been diluted 1: 3 prior to testing). The average starting λ_{max} is shown in brackets.

Excel file: Temperature stability uncoated.xlsx

Spreadsheet: All position grph (2)

Data: In spreadsheet – All - columns F – M, starting at row 7 - highlighted in light gold

Figure K.13 Change in Ab_{max} with exposure to a temperature of 70 °C for the mid λ NF and various different Ag NPr NFs (the mid λ NF has been diluted 1: 3 prior to testing).

Excel file: Temperature stability uncoated.xlsx

Spreadsheet: All Abmax grph (2)

Data: In spreadsheet – All - columns T – Z, starting at row 7 - highlighted in light grey

Table K.3 Unpaired two-sample t-test results for Ag NPrs and mid λ NF before and after exposure to elevated temperature (unpaired two-sample t-test used as the before and after samples were different sub-samples from the main sample). Only the significant differences are shown.

Excel file: Temperature stability uncoated.xlsx

Data: In spreadsheet – mid – as highlighted in pink and in spreadsheet – NPr, columns G – P, rows 1 - 4, CW – CY, rows 5 -8 – as highlighted in purple

Figure K.14 UV-vis spectra of Ag TSCD-PVP NPrs centrifuged and re-dispersed into $\frac{1}{4}$ volume of water before and after SSL exposure using set-up A for 12 h. Measured using a 4 mm path length plastic cuvette and UV-vis-1.

Excel file: SSL stability uncoated.xlsx

Spreadsheet: Ag NPr ct grph

Data: In spreadsheet – UV for grphs - columns A - G - highlighted in light grey

Figure K.15 UV-vis spectra of Ag TSCD-PVP NPr (long λ) before and after 0.5 h exposure to SSL using set-up B. Measured using a 10 mm path length plastic cuvette and UV-vis-IR-1.

Excel file: SSL stability uncoated.xlsx

Spreadsheet: long grph

Data: In spreadsheet – UV for grphs - columns I - O - highlighted in light pink

Figure K.16 UV-vis spectra of short λ before and after 0.5 h exposure to SSL using set-up B. Measured using a 10 mm path length plastic cuvette and UV-vis-IR-1. The short λ NF was diluted 1: 5 prior to testing.

Excel file: SSL stability uncoated.xlsx

Spreadsheet: short grph

Data: In spreadsheet – UV for grphs - columns Q - W - highlighted in green

Figure K.17 UV-vis spectra of mid λ before and after 0.5 h exposure to SSL using set-up B. Measured using a 10 mm path length plastic cuvette and UV-vis-IR-1. The mid λ NF was diluted 1: 3 prior to testing.

Excel file: SSL stability uncoated.xlsx

Spreadsheet: Mid grph

Data: In spreadsheet – UV for grphs - columns Y – AE - highlighted in light gold

Table K.4 Change in $\eta_{\text{lamp}(330 \text{ nm} - 1100 \text{ nm})}$ OR $\eta_{\text{lamp}(330 \text{ nm} - 900 \text{ nm})}$ following exposure to SSL for various different NFs.

Excel file: Lamp vs G173 solar broadband AE lamp cal.xlsx

Data: In spreadsheet – AE lamp spec – Columns GH – HE, HL – HN, HR – HT, row 2407 and 2413 as highlighted in orange

Table K.5 Changes in efficiencies ($\eta_{\text{Ab}(300 \text{ nm} - 1350 \text{ nm})}$ and $\eta_{\text{Ab}(280 \text{ nm} - 4000 \text{ nm})}$) for the broadband absorber and component NFs after exposure to SSL for 0.5 h using set-up B.

Excel file: AE calculations broadband.xlsx

Data: In spreadsheet – absorbance - Sample name in row 7 starting at column DF - HT, data in row 1060, 1061 as highlighted in blue

Appendix L

Table L.1 λ_{\max} and change in λ_{\max} with exposure to an elevated temperature of 70 °C for Ag TSCD NPrs + water-glass SiO₂ re-dispersed into ¼ volume of water BF. Measured on UV-vis-1 using a 1 mm path length quartz cuvette. Positive is a red-shift.

Excel file: Water glass UV-vis.xlsx

Data: In spreadsheet – data - column BL - CD, data in rows 8 and 9, sample name row 11 as highlighted in light pink

Table L.2 Ab_{\max} and change in Ab_{\max} with exposure to an elevated temperature of 70 °C for Ag TSCD NPrs + water-glass SiO₂ re-dispersed into ¼ volume of water BF. Positive is an increase.

Excel file: Water glass UV-vis.xlsx

Data: In spreadsheet – data - column BL - CD, data in rows 6 and 7, sample name row 11 (highlighted in light pink) - data highlighted in light purple

Table L.3 λ_{\max} and change in λ_{\max} with exposure to an elevated temperature of 70 °C for Ag TSCD NPrs + water-glass SiO₂ re-dispersed into ¼ volume of PG BF. Measured on UV-vis-1 using a 10 mm path length plastic micro-cuvette. Positive is a red-shift.

Excel file: Water glass UV-vis.xlsx

Data: In spreadsheet – data - column CF - CX, data in rows 8 and 9, sample name row 11 - highlighted in blue

Table L.4 Ab_{\max} and change in Ab_{\max} with exposure to an elevated temperature of 70 °C for Ag TSCD NPrs + water-glass SiO₂ re-dispersed into ¼ volume of PG BF. Measured on UV-vis-1 using a 10 mm path length plastic micro-cuvette. Positive is an increase.

Excel file: Water glass UV-vis.xlsx

Data: In spreadsheet – data - column CF - CX, data in rows 6 and 7, sample name row 11 (highlighted in blue) – data highlighted in green

Figure L.1 UV-vis spectra before and after SiO₂ coating using the water-glass method. All measured using UV-vis-1. The after centrifuged samples have been adjusted for cuvette and concentration. Error bars show range of results obtained at the maximum absorbance ($N = 3$).

Excel file: Water glass UV-vis.xlsx

Spreadsheet: cent and MPTMS grphs

Data: In spreadsheet – data - columns AX – BI - highlighted in light gold

Figure L.2 Summary of the TEM analysis for the water-glass SiO₂ coating method.

Excel file: TEM water glass SiO₂.xlsx

Spreadsheet: grph

Data: In spreadsheet – percents - columns A – E, rows 17 - 26- highlighted in blue

Figure L.3 Variation of the SiO₂ coating thickness obtained from the TEM analysis with concentration of TEOS used for the Stöber coating method. The error bars show the standard deviation σ .

Excel file: TEM development of TEOS method.xlsx

Spreadsheet: conc grph

Data: In spreadsheet – for grphs - columns N - V- highlighted in pink

Figure L.4 Percentages of multi-cored NPs (excluding SiO₂ only NPs) and Ag free (not SiO₂ coated) obtained from the TEM analysis for the Stöber SiO₂ coating process optimisation.

Excel file: TEM development of TEOS method.xlsx

Spreadsheet: % multi and free grphs

Data: In spreadsheet – for grphs - columns A – H, rows 17 – 19 - highlighted in purple

Appendix M

Table M.1 UV-vis results before SiO₂ coating. Measured using a 10 mm path length cuvette.

Excel file: TEOS standard method as made UV vis.xlsx

Data: In spreadsheet – data - column A – H and R – W, rows 12 - 16 – data highlighted in light pink

Table M.2 UV-vis results after employing the optimised Stöber process. Measured using UV-vis-1.

The Ab_{max} values have been adjusted for dilution and cuvette.

Excel file: TEOS standard method as made UV vis.xlsx

Data: In spreadsheet – data - column J – P, rows 12 - 16 – data highlighted in blue

Table M.3 UV-vis results after employing the optimised Stöber process. Measured using UV-vis-IR-2.

The Ab_{max} values have been adjusted for dilution and cuvette. The letters in the sample name refer to subsamples and the numbers the main sample.

Excel file: TEOS standard method as made UV vis.xlsx

Data: In spreadsheet – data - column Y – AJ, rows 12 - 16 – data highlighted in green

Figure M.1 UV-vis spectra before and after SiO₂ coating using the optimised Stöber process measured using UV-vis-1. The SiO₂@Ag NPrs have been adjusted for dilution and cuvette. Average values shown ($N = 7$). Error bars show range of results at the maximum absorbance.

Excel file: TEOS standard method as made UV vis.xlsx

Spreadsheet: UV-vis-1 grph

Data: In spreadsheet – data - columns AL – AP - highlighted in light grey

Figure M.2 UV-vis spectra before and after SiO₂ coating using the optimised Stöber process measured using UV-vis-IR-2. The SiO₂@Ag NPrs have been adjusted for dilution and cuvette. Average values shown (some SiO₂@Ag NPr samples were split for subsequent testing – hence total N after = 12). Error bars show range of results at the maximum absorbance.

Excel file: TEOS standard method as made UV vis.xlsx

Spreadsheet: UV-vis-IR-2 grph

Data: In spreadsheet – data - columns AR – AX - highlighted in orange

Figure M.3 Percentages of multi-cored NPs (excluding SiO₂ only NPs) and Ag free (not SiO₂ coated) obtained from the TEM analysis for the Stöber SiO₂ coating process (just synthesised). Both SiO₂@Ag NPr development and SiO₂@Ag NPr – 7 produced using a smaller batch volume.

Excel file: Standard TEOS method TEM initial SiO2.xlsx

Spreadsheet: % multi and free grph

Data: In spreadsheet – For grphs - columns A – L, rows 7 - 9 - highlighted in orange

Figure M.4 Typical TEM micrographs of the as produced standard TEOS SiO₂ coating showing (A) SiO₂@Ag NPr-1, (B) SiO₂@Ag NPr-4, (C) SiO₂@Ag NPr-7, and (D) SiO₂@Ag NPr-11. All produced using 40 μM MHA and 10 mM TEOS for 30 minutes. All red scale bars = 100 nm.

Power point: TEM standard TEOS just made.pptx

Image file:TEM standard TEOS initial.jpg

Table M.4 Estimated η_{Ab} values for just synthesised SiO₂@Ag NPrs re-dispersed into ¼ volume of water using a 10 mm path length.

Excel file: TEOS standard method as made UV vis.xlsx

Data: In spreadsheet – Summarised AE – columns E – N, rows 2 and 3 - highlighted in orange

Table M.5 Change in UV-vis spectra following storage in the dark at 4 °C for SiO₂@Ag NPRs re-dispersed into ¼ volume of water. Measured using UV-vis-1.

Excel file: SiO₂ standard colloidal stability.xlsx

Data: In spreadsheet – Data – columns A – T, rows 13 - 18 - highlighted in orange

Figure M.5 Typical TEM micrographs of the standard TEOS SiO₂ coating showing (A) SiO₂@Ag NPR-1 initial, (B) SiO₂@Ag NPR-1 after 51 days, (C) SiO₂@Ag NPR-2 after 49 days, and (D) SiO₂@Ag NPR-3 after 49 days in the dark at 4 °C. All produced using 40 µM MHA and 10 mM TEOS for 30 minutes. All red scale bars = 100 nm.

Power point: TEM standard TEOS colloidal stability.pptx

Image file:TEM standard TEOS colloidal stability.jpg

Figure M.6 Change in λ_{\max} with exposure to a temperature of 70 °C for SiO₂@Ag NPR NFs with different NF concentrations.

Excel file: SiO₂ Standard temperature stability.xlsx

Spreadsheet: Change in position grph

Data: In spreadsheet – time data - columns I – L, rows 29 - 108 - highlighted in orange

Figure M.7 Change in Ab_{\max} with exposure to a temperature of 70 °C for SiO₂@Ag NPR NFs with different NF concentrations. Note that one sample was excluded from the SiO₂@Ag NPR diluted results as it was not correctly sealed resulting in a large increase in Ab_{\max} due to evaporation, hence $N = 2$ rather than 3.

Excel file: SiO₂ Standard temperature stability.xlsx

Spreadsheet: Abmax change grph

Data: In spreadsheet – time data - columns B – E, rows 29 - 108 - highlighted in blue

Table M.6 Change in λ_{\max} after 9 h exposure to an elevated temperature of 70 °C (positive = red-shift).

Excel file: SiO₂ Standard temperature stability.xlsx

Data: In spreadsheet – time data - columns T – W, rows 29 - 54 - highlighted in light gold

Table M.7 Change in Ab_{\max} after 9 h exposure to an elevated temperature of 70 °C (positive = increase).

Excel file: SiO₂ Standard temperature stability.xlsx

Data: In spreadsheet – time data - columns O – S, rows 29 - 54 - highlighted in light pink

Table M.8 Results of undertaking ANOVA on the samples after 9 h at 70 °C for the change in Ab_{\max} (positive = increase). The average values and the potential range of the average value are shown along with the grouping. Groups that do not share a letter are significantly different.

Excel file: SiO2 Standard temperature stability.xlsx

Data: In spreadsheet – time data - columns AV - BD, rows 10 - 69 - highlighted in light purple

Table M.9 Results of undertaking ANOVA on the samples after 9 h at 70 °C for the change in λ_{\max} (positive = red shift). The average values and the potential range of the average value are shown along with the grouping. Groups that do not share a letter are significantly different.

Excel file: SiO2 Standard temperature stability.xlsx

Data: In spreadsheet – time data - columns BF - BN, rows 10 - 68 - highlighted in light grey

Figure M.8 Average UV-vis spectra for SiO₂@Ag NPR re-dispersed into ¼ volume of water (compared to original NF volume) before and after exposure to SSL for 6 h using set-up A in the solar simulator. The error bars show the range of results obtained at the maximum absorbance for the three repeat synthesis. Measured using UV-vis-1 and a 1 mL 4 mm path length disposable cuvette.

Excel file: SiO2 standard SSL stability.xlsx

Spreadsheet: average before after

Data: In spreadsheet – data - columns AH – AL, starting at row 18 - highlighted in blue

Figure M.9 Typical TEM micrographs of the standard TEOS SiO₂ coating showing (A) SiO₂@Ag NPR-1 before SSL exposure, (B) SiO₂@Ag NPR-1, (C) SiO₂@Ag NPR-2, and (D) SiO₂@Ag NPR-3 after 6 h exposure to SSL. All produced using 40 µM MHA and 10 mM TEOS for 30 minutes. All red scale bars = 100 nm.

Power point: TEM standard TEOS SSL stability.pptx

Image file: TEM standard TEOS SSL stability.jpg

Appendix N

Table N.1 UV-vis parameters for SiO₂@Ag NPRs with and without an extra purification step (either at start of procedure or at end). All re-dispersed into ¼ volume of water compared to the original NF and measured using UV-vis-1 and a 1 mm quartz cuvette.

Excel file: modifications to SiO2.xlsx

Data: In spreadsheet – extra wash and O₂ removal - columns P - AA, rows 6 - 11 – as highlighted in pink

Table N.2 UV-vis parameters for SiO₂@Ag NPrs with and without the level of oxygen in the NFs reduced. All re-dispersed into ¼ volume of water compared to the original NF and measured using UV-vis-1 and a 1 mm quartz cuvette.

Excel file: modifications to SiO₂.xlsx

Data: In spreadsheet – extra wash and O₂ removal - columns B - F, rows 7 - 11 – as highlighted in orange

Table N.3 Details of the preliminary experiments to investigate the effect of MHA and DMA on Ag TSCD-PVP NPrs.

Excel file: modifications to SiO₂.xlsx

Data: In spreadsheet – role of reagents - columns A - H, rows 7 - 13 – as highlighted in light grey

Table N.4 Summarised UV-vis results for SiO₂@Ag NPrs produced using no capping agent MHA. Measured using UV-vis-1.

Excel file: modifications to SiO₂.xlsx

Data: In spreadsheet – MHA DMA – column T, X, AF, AJ, rows 19, 21 and 22 – as highlighted in blue

Table N.5 Summary of UV-vis results for SiO₂@Ag NPrs re-dispersed into ¼ volume of water (compared to the original starting NF volume) produced using 40 µM MHA and the normal concentration of DMA (the optimised Stöber process from Section 3.6.4). Measured using UV-vis-1.

Excel file: modifications to SiO₂.xlsx

Data: In spreadsheet – MHA DMA – column AW, AT, AQ, AM and AN - rows 6 -14 – as highlighted in green

Table N.6 Summary of UV-vis results for SiO₂@Ag NPrs re-dispersed into ¼ volume of water (compared to the original starting NF volume) produced using 160 µM MHA and the normal concentration of DMA. Measured using UV-vis-1.

Excel file: modifications to SiO₂.xlsx

Data: In spreadsheet – MHA DMA – column AO, AP, AR, AU, AX - rows 6 -14 – as highlighted in orange

Figure N.1 UV-vis spectra before, after SiO₂ coating and after 12 h @ 70 °C for SiO₂@Ag NPrs produced using ¼ concentration of DMA. Measured using UV-vis-1. Results have been adjusted for final NF volume and cuvette employed.

Excel file: modifications to SiO₂.xlsx

Spreadsheet: low DMA grph

Data: In spreadsheet – low DMA - columns H – M, starting at row 7 - highlighted in light pink

Figure N.2 UV-vis spectra before and after SiO₂ coating using a TEOS reaction time of 1 minute or 5 minutes. Measured using UV-vis-IR-2. Values have been adjusted for cuvette and dilution. Average of 3 results shown with error bars showing range of results obtained at the maximum absorbance.

Excel file: modifications to SiO2.xlsx

Spreadsheet: TEOS time grph

Data: In spreadsheet – TEOS step time - columns CB – CH, starting at row 6 - highlighted in green

Figure N.3 Change in λ_{\max} with exposure to a temperature of 70 °C for SiO₂@Ag NPr NFs produced using two different TEOS reaction times.

Excel file: modifications to SiO2.xlsx

Spreadsheet: TEOS time change in pos grph

Data: In spreadsheet – TEOS time for grph - columns J – L, starting at row 25 - highlighted in pink

Figure N.4 Change in Ab_{\max} with exposure to a temperature of 70 °C for SiO₂@Ag NPr NFs produced using two different TEOS reaction times.

Excel file: modifications to SiO2.xlsx

Spreadsheet: TEOS time change in abmax grph

Data: In spreadsheet – TEOS time for grph - columns A – C, starting at row 25 - highlighted in purple

Table N.7 Change in λ_{\max} after 9 h exposure to an elevated temperature of 70 °C (positive = red-shift).

Excel file: modifications to SiO2.xlsx

Data: In spreadsheet – TEOS time for grph – column S - V - rows 25 - 50 – as highlighted in light grey

Table N.8 Change in Ab_{\max} after 9 h exposure to an elevated temperature of 70 °C (positive = increase).

Excel file: modifications to SiO2.xlsx

Data: In spreadsheet – TEOS time for grph – column N - Q - rows 25 - 50 – as highlighted in green

Appendix O

Figure O.1 Amount of power absorbed P_{Ab} of the G173 ($G_{s,\lambda(\text{dir} + \text{cs})}$) with a 10 mm path length by the broadband absorber before and after SiO₂ coating. The secondary vertical axis is for the G173 solar spectrum taken from ([ASTM, 2012](#)).

Excel file: SiO₂ coated broadband.xlsx

Spreadsheet: power grph

Data: In spreadsheet – performance cal - columns A – D - highlighted in green

Table O.1 Various different efficiency calculations for the broadband absorber before and after SiO₂ coating.

Excel file: SiO₂ coated broadband.xlsx

Data: In spreadsheet – performance cal - columns G – I, rows 3 - 8 - highlighted in blue

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