Supplementary Information

SnO_2 shell for high environmental stability of Ag nanowires applied for thermal management

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ABSTRACT

Since silver nanowires (AgNWs) show high infrared reflectance many studies present their applicability as thermal management products for various wearable textiles. However, their use for practical purposes is only partially evaluated, without focusing on improving their low atmospheric and liquid stability. This report describes a new approach for the topic and propose a facile method of Ag nanowires passivation with an SnO_2 layer for high environmental stability and retain high infrared reflectance. The one-step passivation process of AgNWs was carried out in the presence of sodium stannate in an aqueous solution at 100 °C, and resulted in the formation of core/shell Ag/SnO_2 nanowires. This study presents

the morphological, chemical, and structural properties of Ag/SnO_2NWs formed by a 14 nm thick SnO_2 shell, consisting of 7 nm rutile-type crystals, covering the silver metallic core. The optical properties of the AgNWs changed significantly after the shell formation, the longitudinal and transverse modes in the surface plasmon resonance spectrum were red shifted as a result of the surrounding media dielectric constant changes.

The passivation process protected the AgNWs from decomposition in the air for over 4 months, and from dissolution in a KCN solution at the concentration up to 0.1 wt.%. Moreover, the report shows the microwave irradiation effect on the shell synthesis and previously synthesised Ag/SnO_2NWs. The post-synthesis irradiation, as well as the SnO_2 shell obtained by microwave assistance, and did not allow long-term stability to be achieved. The microwave-assisted synthesis process was also not fast enough to inhibit the formation of prismatic silver structures from the nanowires.

The Ag/SnO_2NWs with the shell obtained by the simple hydrolysis process, apart from showing high infra-red reflectance on the para-aramid fabric are highly environmentally resistant. The presented SnO_2 shell preparation method can protect the AgNW's surface from dissolution or decomposition and facilitate the designing of durable smart wearable thermal materials for various conditions.

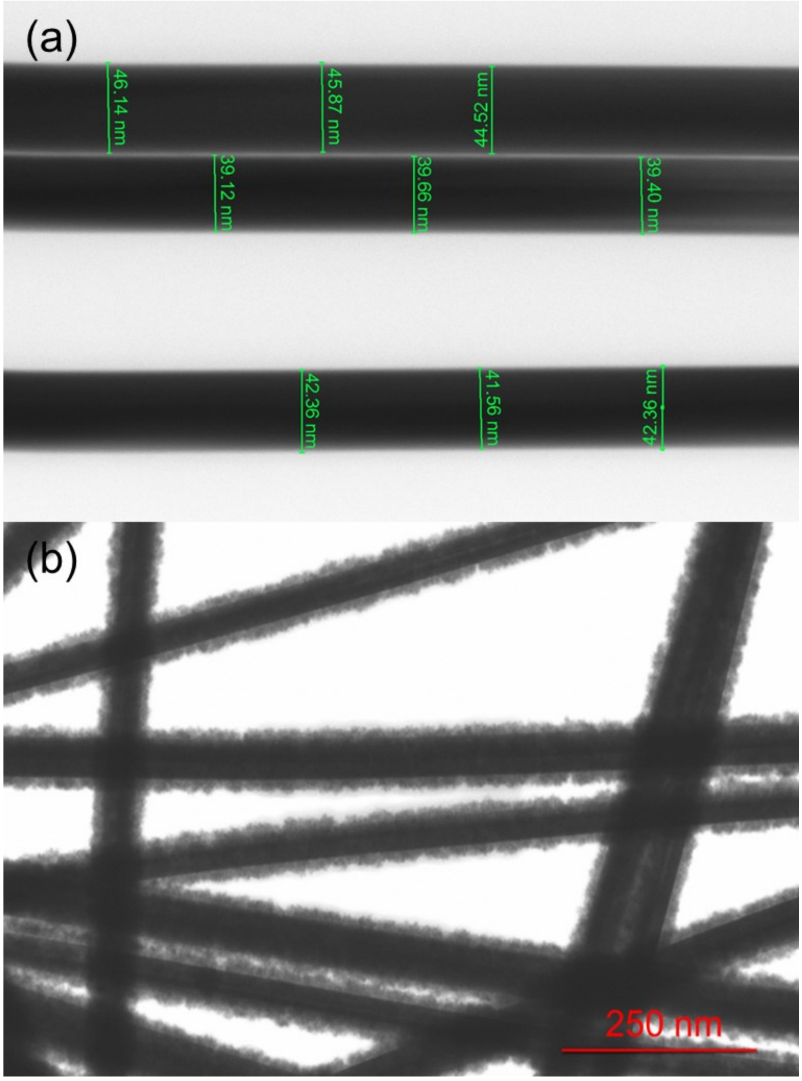

Fig. S1 STEM images of (a) AgNWs and (b) core/shell Ag/SnO_2NWs. The SnO_2 shell was obtained without microwave irradiation assistance.

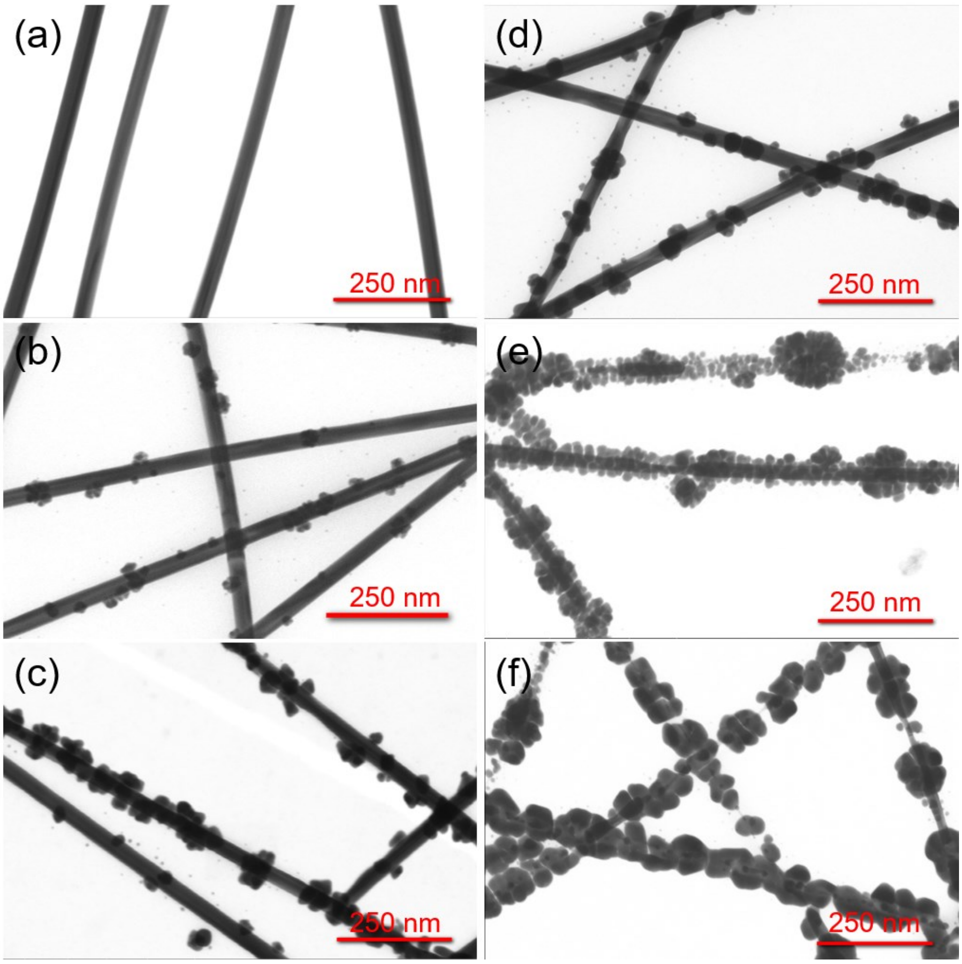

Fig. S2 STEM images of AgNWs (a) after the synthesis and further exposure to the air at room temperature for (b) 1, (c) 2, (d) 3, (e) 7 and (f) 9 weeks.

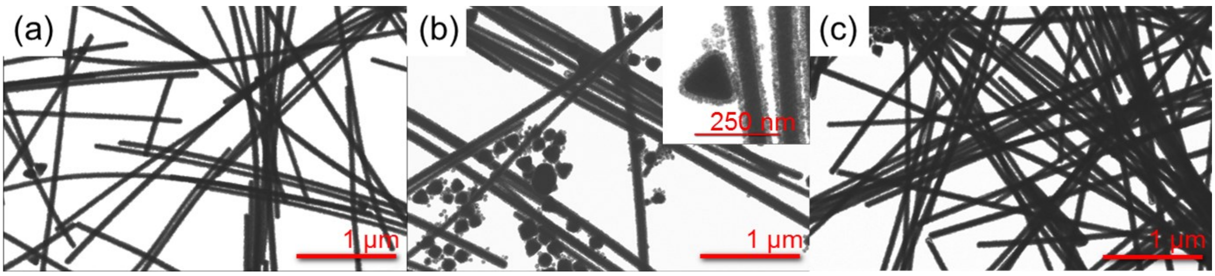

Fig. S3 STEM images of core/shell Ag/SnO_2NWs nanowires. (a) The SnO_2 shell was obtained in aqueous solution at 100 °C, (b) under microwave irradiation at 100 °C and (c) treated with microwave irradiation after the synthesis in aqueous solution at 100 °C.

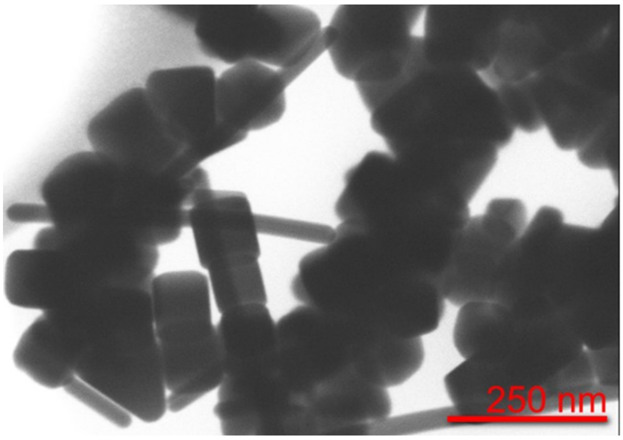

Fig. S4 STEM image of AgNWs treated with microwave irradiation.

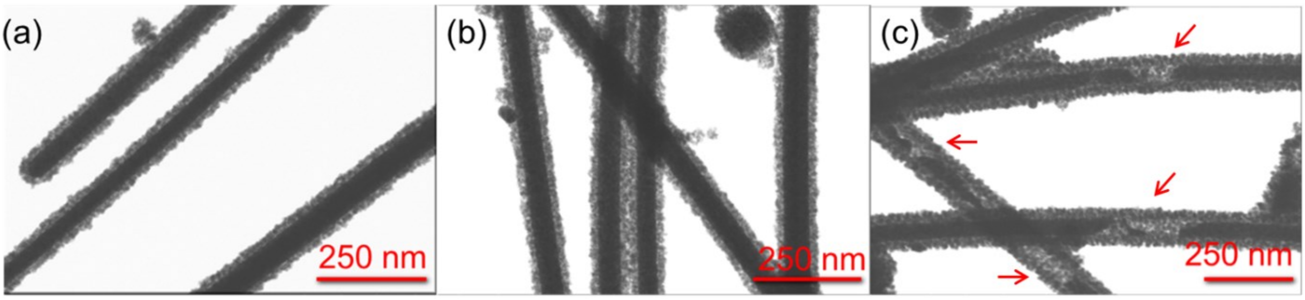

Fig. S5 STEM images of core/shell Ag/SnO_2NWs (a) after the synthesis, (b) 3 weeks and (c) 4 months kept in air at room temperature. The SnO_2 shell was obtained with microwave irradiation assistance.

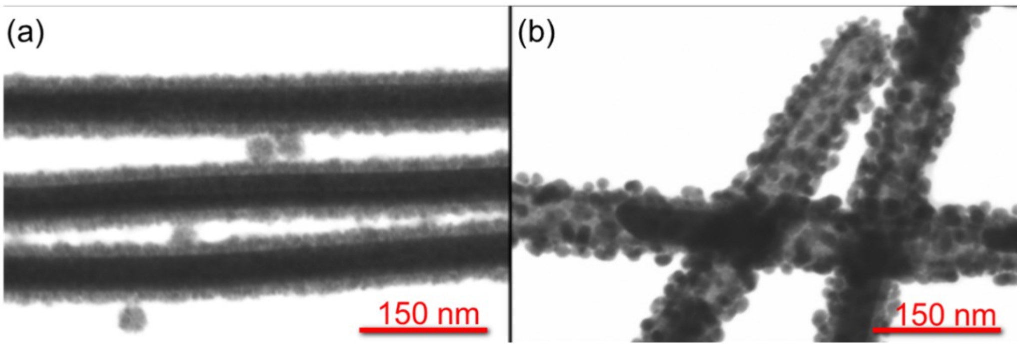

Fig. S6 STEM images of core/shell Ag/SnO_2NWs (a) after the synthesis and (b) 5 weeks kept in air at room temperature. Ag/SnO_2NWs were treated with microwave irradiation after the shell synthesis in aqueous solution at 100 °C.

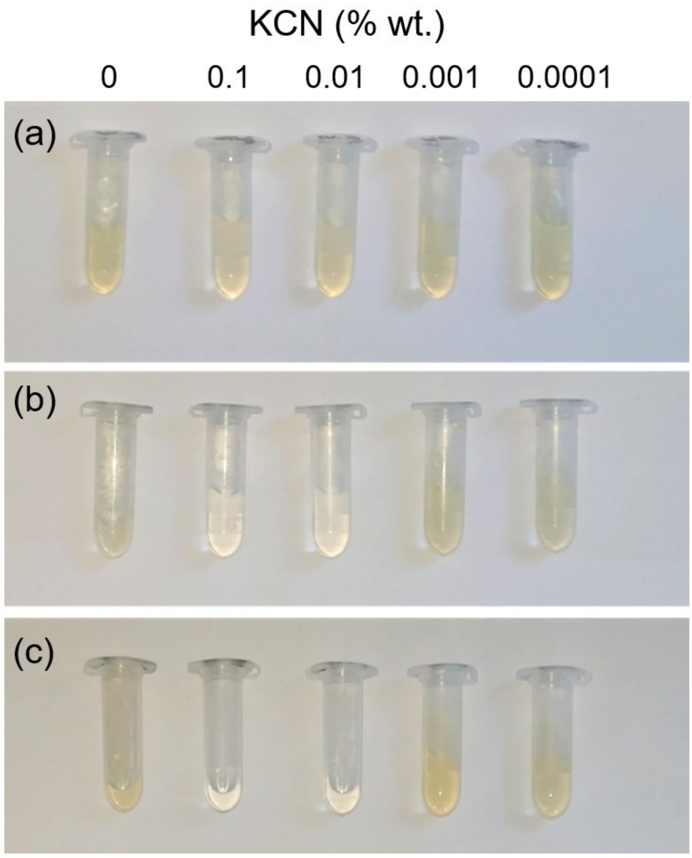

Fig. S7 Images of aqueous core/shell Ag/SnO_2NWs solutions. The nanostructures obtained (a) (a), (c) without and (b) with microwave irradiation assistance and (c) also treated with microwave irradiation after the shell synthesis process. The samples were treated with 0, 0.1, 0.01, 0.001, 0.0001% wt. KCN.

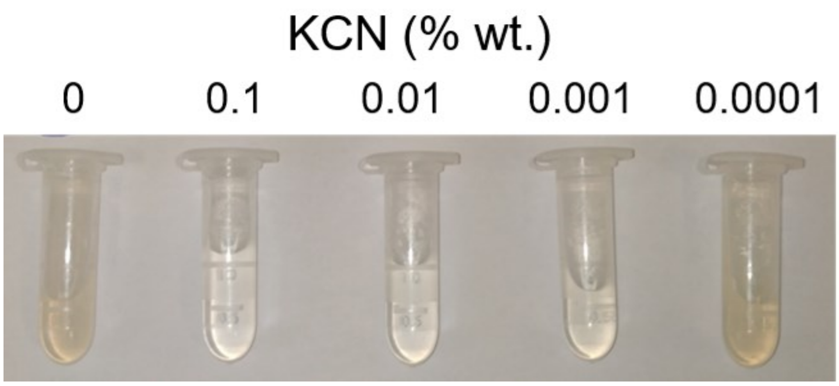

Fig. S8 Images of aqueous AgNWs solutions. The samples were treated with 0, 0.1, 0.01, 0.001, 0.0001% wt. KCN.

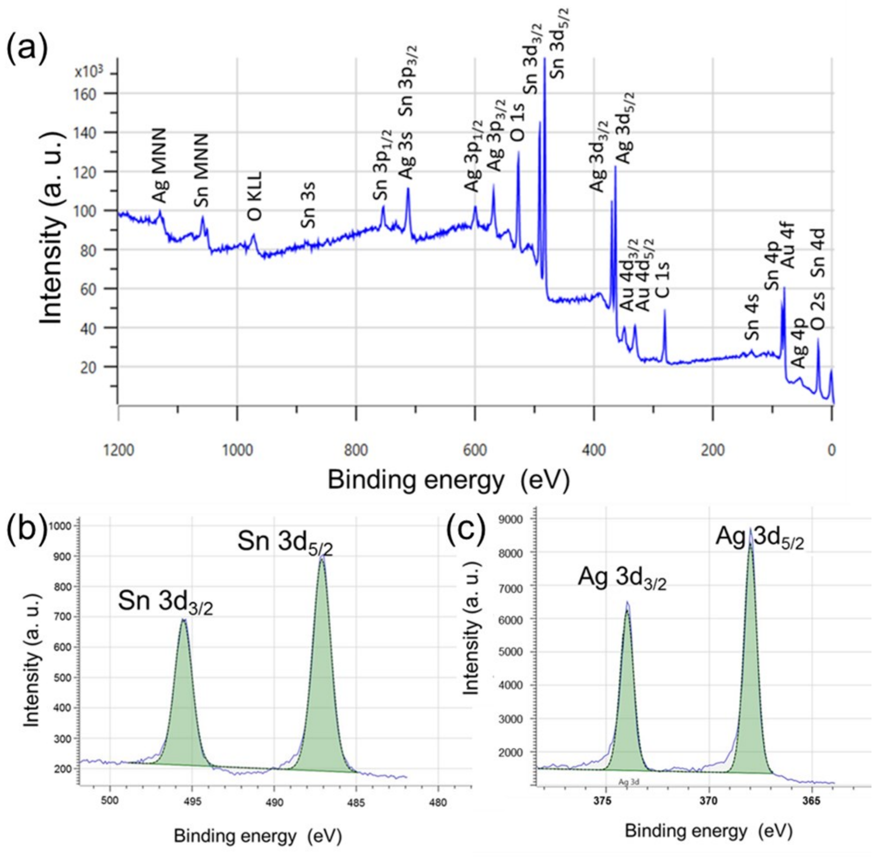

Fig. S9 (a) XPS survey spectrum and core level XPS (b) Sn 3d and (c) Ag 3d of Ag/SnO_2NWs. The SnO_2 shell was obtained at 100 °C without microwave treatment.

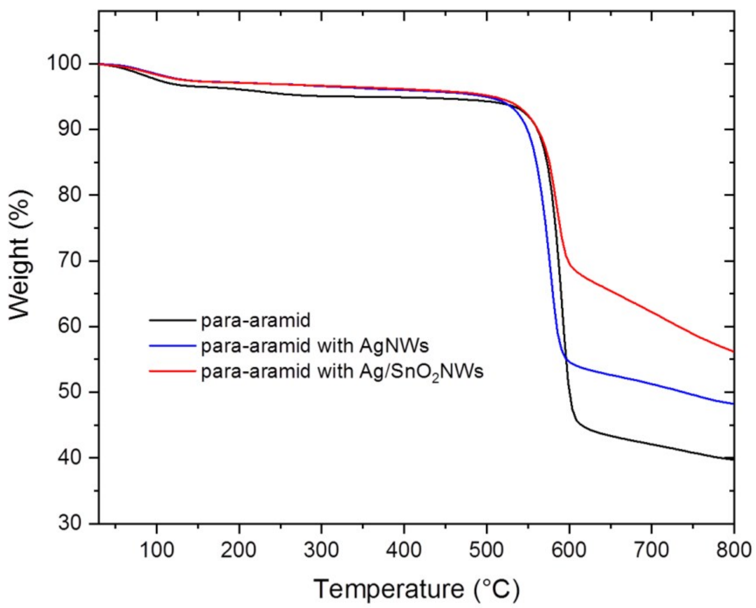

Fig. S10 TG thermograms of pure para-aramid fabric and with deposited AgNWs and Ag/SnO_2NWs.

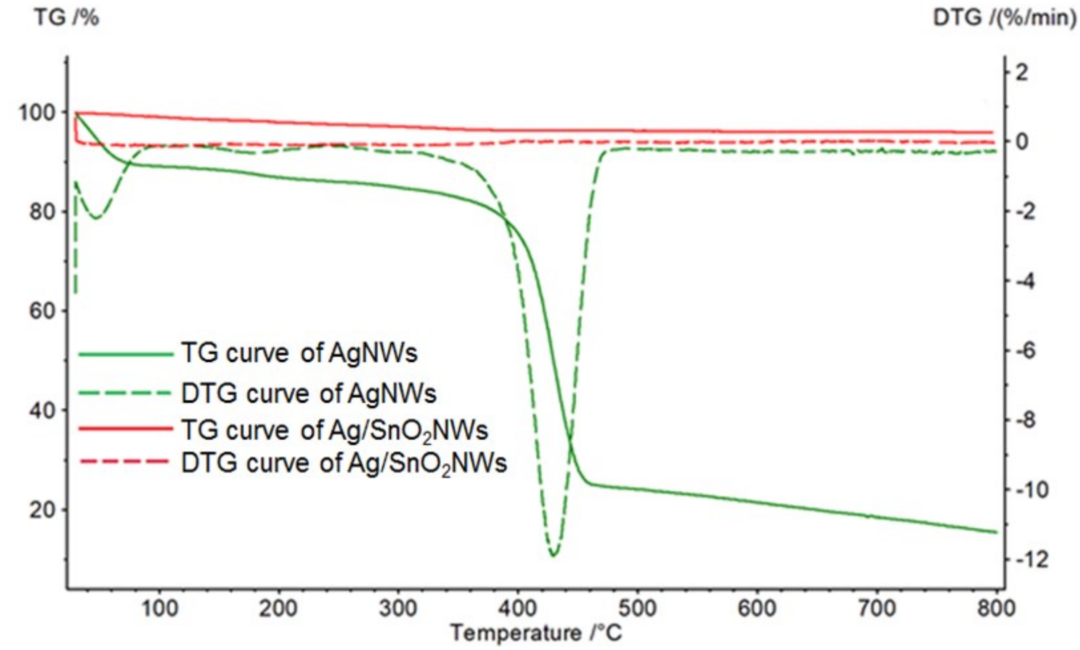

Fig. S11 TG/DTG thermograms of AgNWs and core/shell Ag/SnO_2NWs powders.

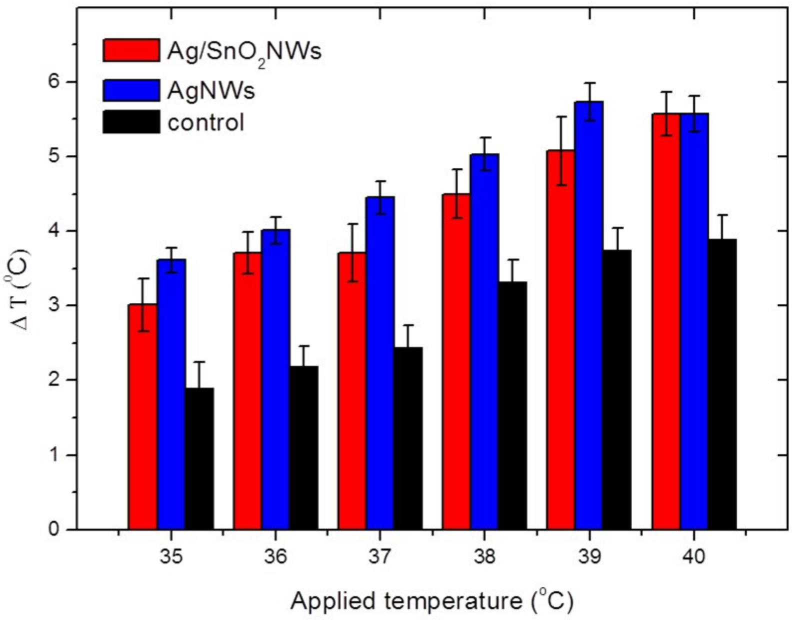

Fig. S12 Heat transfer measurement by the temperature increase after placing the para-aramid cloth with deposited Ag/SnO_2NWs, AgNWs samples and without nanowires (control sample) on an open-air hot plate of the range of 35 to 40 °C.