Enhanced Performance of Quantum Dots Sensitized Solar Cell Utilizing Copper Indium Sulfide and Reduced-Graphene Oxide with the Presence of Silver Sulfide

NURUL SYAFIQAH MOHAMED MUSTAKIM, MUHAZRI ABD MUTALIB, SUHAILA SEPEAI, NORASIKIN AHMAD LUDIN, MOHD ASRI MAT TERIDI & MOHD ADIB IBRAHIM*

ABSTRACT

In this study, rGO/CuInS₂ has been successfully prepared onto TiO₂ thin film using solvothermal method followed by Ag₂S deposition layer by successive ionic layer adsorption and reaction deposition (SILAR) technique. The morphology, structural, and optical properties of TiO₂/rGO/CuInS₂ thin film were investigated by using field emission scanning electron microscopy (FESEM), energy-dispersive X-ray spectroscopy (EDX), atomic force microscope (AFM), X-ray diffraction (XRD) and ultra-violet-visible near infrared spectrophotometer (UV-VIS). For electrical properties, electrochemical impedance spectra (EIS) and current-voltage (I-V) test investigated the interfacial charge-transfer resistances and the conversion efficiency of the samples. Results showed that the average particles size of the samples ranged from ±46.52 to ±53.97 nm in diameter. UV-VIS analysis indicated that TiO₂/rGO/CuInS₂ thin film showed better light absorption capability with the presence of Ag₂S deposition layers. The rGO/CuInS₂ quantum dot sensitized with Ag₂S layers exhibit a photovoltaic power conversion efficiency of 0.33%, which has great improvement of short circuit current (I_sc) comparing with that of rGO/CuInS₂ quantum dot sensitized without Ag₂S deposition layers.

Keywords: Ag₂S; CuInS₂; quantum dots; rGO; SILAR; solar cells; solvothermal

INTRODUCTION

The range of materials and structures of solar cells is very important to achieve good photovoltaic devices (Kouhnavard et al. 2014). Due to its extra-ordinary properties, graphene shows promising applications in many fields such as photovoltaic devices, nanoelectrochemical systems, nanoelectronics, and mechanical alloying (Ubani et al. 2016; Zhang et al. 2015a). Basically, graphene is a mono-layer structure of two-dimensional graphite which makes it an ideal material to has the ability as a larger donor-accepter interface with quantum dots (QDs) material. Besides, since the work function
of this semi metallic graphene is 4.5 eV, it is capable of dissociating excitons that generated in the QDs (Kumari et al. 2014). It is highly transparent as well as able to absorbs 2.3% of incident white light which making it highly suitable for photo anode applications in solar cell devices (Madhavan et al. 2012). According to Kumari et al. (2014), the presence of graphene in photovoltaic applications are likely to produce better stability of the devices.

The application of CuInS$_2$ QDs in photovoltaic application have already been studied due to its unique properties such as non-toxicity material and high absorption coefficient. There are various synthesis methods including solid state reaction, hot injection method, chemical bath deposition, solvothermal and SILAR technique have been applied to prepare CuInS$_2$ nanostructures (Hosseinpour-Mashkani et al. 2014, Mustakim et al. 2018). However, the power conversion efficiency the current CuInS$_2$ based QDSSCs is still low and not satisfactory for practical application to be commercialized.

On the other hand, introduction of passivation layer in QDSSCs has been proved can help to enhance the performance of solar cells (Peng et al. 2014). Thin layer that passivate the QDs could improve QDs stability and promote electron injection from the QDs to the photo anode. It can also prevent leakage of current from the QDs to electrolyte, which can enhance the performance of QDSSCs. According to Holi et al. (2017), Ag$_S$ is one of the best materials to be used in solar cells since it is environmentally benign material. In addition, Ag$_S$ has a large absorption coefficient and a direct band gap of 0.9 to 1.05 eV which is equal to the optimal band gap of 1.13 eV for a photovoltaic device (Tubtimtae et al. 2010).

Therefore, the aim of this study was to investigate the performance of the CuInS$_2$ quantum dot and rGO with and without the presence of Ag$_S$ as interface layer on the QDSSCs. The morphology, structural, optical, and electrical properties of nanostructured CuInS$_2$ QDs and the rGO as an effective photosensitizer and the presence of Ag$_S$ layers in solar cell were carried out during the investigation. From this study, the optimum performance of environment friendly TiO$_2$/rGO/CuInS$_2$/Ag$_S$ thin films can be applicable as a photoanode for QDSSCs.

**MATERIALS AND METHODS**

**MATERIALS**

All reagents including hydrochloric acid (HCl, 36.5% - 38%; J.T. Baker), titanium chloride (TiCl$_4$, 99%; Merck), graphene oxide (rGO) powder, cupric acetate monohydrate (Cu(AC)$_2$, H$_2$O, 99%; Merck), indium acetate (In(AC)$_3$, 99.99%; Sigma Aldrich), octadecylamine (90%; Merck), thiourea (CS(NH)$_2$, 99%; Sigma Aldrich), silver nitride (AgNO$_3$, 99.8%; R&M Chemicals), sodium sulfide (Na$_2$S, Sigma Aldrich), absolute ethanol, and methanol.

**EXPERIMENTAL PROCEDURES**

TiO$_2$ nanoparticles has been synthesized onto cleaned FTO glass using modified hydrothermal method by Han et al. (2015). The 15 mL of deionized (DI) water was mixed with 15 mL of HCl. The mixture was stirred for 5 min followed by 0.5 mL TiCl$_4$. The mixture was stirred for another 5 min and then placed in a Teflon-lined stainless-steel autoclave. Then, one piece of FTO substrate was placed at an angle against the wall of the Teflon liner with the conductive side facing down. A reaction temperature of 180 °C was used for 10 h reaction time. After synthesis, the autoclave was cooled down to room temperature. Then the FTO substrate was rinsed extensively with DI water and allowed to dry in ambient air. Lastly, annealed at 450 °C for 30 min.

The rGO/CuInS$_2$ QDs was prepared using modified solvothermal method by Yue et al. (2014). Firstly, 2.5 mg of rGO powder was dispersed in 50 mL absolute ethanol by ultrasonication to obtain a homogeneous suspension. Then, 0.05 mmol of Cu(AC)$_2$, H$_2$O was dispersed followed by additional of In(AC)$_3$ (0.05 mmol) into the dispersion. 0.60 mmol of octadecylamine was ultrasonically dissolved into the dispersion. Next, 0.2 mmol CS(NH)$_2$ was added and a dark-coloured dispersion was produced which also known as CuInS$_2$ precursor. The CuInS$_2$ precursor was then transferred into a Teflon-lined stainless-steel autoclave with TiO$_2$ thin film that placed at an angle against the wall of the Teflon liner with the conductive side facing down. The autoclave was heated at 160 °C for 8 h reaction time.

After the autoclave naturally cooled to room temperature, the product was collected by centrifugation (10,000 rpm, 8 min), washed several times with absolute ethanol and dried under N$_2$ at 60 °C for 3 h.

A modified SILAR technique by Zhang et al. (2015b) was used to deposit Ag$_S$ layer onto TiO$_2$/rGO/CuInS$_2$ thin film. Briefly, TiO$_2$/rGO/CuInS$_2$ thin film was dipped into AgNO$_3$ ethanol solution for 3 min, then rinsed with ethanol. Next, TiO$_2$/rGO/CuInS$_2$ thin film was dipped into Na$_2$S methanol solution and rinsed with methanol. These dipped procedures formed one SILAR cycle and was repeated for 6 SILAR cycles. Lastly, dried under ambient air for an hour.

**RESULTS AND DISCUSSION**

**MORPHOLOGICAL PROPERTIES**

Characterization using FESEM was carried out to study the distribution and size of particles of prepared samples.
Based on the observation in Figure 1, it looks like CuInS$_2$ QDs particles were attached to graphene sheet which covered uniformly the whole surface of TiO$_2$ film. From the FESEM images, the average particles size of TiO$_2$/rGO/CuInS$_2$ increased from ±46.52 to ±53.97 nm in diameter after Ag$_2$S deposition as well as the thickness of the samples which increased from 3.38 to 4.39 μm. These increments were due to the aggregation of Ag$_2$S particles that formed after the Ag$_2$S deposition as clearly observed in Figure 2. Basically, larger particle size reduced the gap between the particles, hence reduced the internal surface area of the sample.

Characterization using EDX was performed on TiO$_2$/rGO/CuInS$_2$ thin film before and after deposition of Ag$_2$S layers to determine the presence of each element in the samples. From the analysis in Figure 3, Cu, In, and S elements were detected in the spectra which proved that CuInS$_2$ material were successfully deposited on the TiO$_2$ thin film surface. While Figure 4 shows the Ag element which proved that Ag$_2$S layer was successfully applied onto the TiO$_2$/rGO/CuInS$_2$ thin film. C element that appeared in both spectra shows the existence of graphene in the samples.
AFM characterization was performed to determine the surface roughness of the TiO$_2$/rGO/CuInS$_2$ thin film with and without the Ag$_2$S coating layer. Based on the AFM images in Figure 5, the RMS value increased after the deposition of Ag$_2$S layers which showed that Ag$_2$S were successfully absorbed and cover the surface of the TiO$_2$/rGO/CuInS$_2$ thin film. The RMS value of the TiO$_2$/rGO/CuInS$_2$ thin film slightly increased from 10.79 to 11.60 nm with 6 Ag$_2$S SILAR cycles (Figure 6). The changes in the RMS value indicated that the presence of Ag$_2$S particles in the sample can be attributed to the increase in particle size of the sample as well.
STRUCTURAL PROPERTIES

XRD characterization was carried out to identify the structure of TiO$_2$, graphene, CuInS$_2$, and Ag$_2$S that could be determined from the crystalline phases of the thin film. The R-labelled peak observed in the XRD spectra refers to TiO$_2$ at angles of 36.08° corresponding to the plane (101) of the rutile phase (PDF 01-079-5860). For rGO, there is peak at 26.35° corresponding to (002) plane (PDF-01-089-8487). As observed in Figure 7, the typical peaks of rGO was not found in spectra. According to Meng et al. (2015), the disappearance of the (002) diffraction peak of rGO indicates the destruction of the regular stacks of graphene sheets by exfoliation or intercalation of reactants.

Other peaks began to appear after Ag$_2$S layers were deposited onto the TiO$_2$/rGO/CuInS$_2$ thin film. There are Ag$_2$S peaks at angles of 28.97°, 31.52°, 33.61°, 40.74° and 43.41° corresponding to planes (111), (-112), (120), (031) and (200) acanthite phases (PDF 00-011-0688). However, the peaks for CuInS$_2$ could not be observed in the XRD spectra. This is because TiO$_2$ and Ag$_2$S produced crystalline peaks while CuInS$_2$ produced amorphous peaks. Basically, the crystalline phase has a higher and narrower intensity peak. On the other hand, the amorphous phase has a lower and wider peak intensity. Different peaks in the same spectra cause the amorphous peaks to be less prominent compared to the crystalline peaks. Additionally, there are other peaks present in the spectra that may refer to the FTO glass itself.

FIGURE 6. Surface roughness of TiO$_2$/rGO/CuInS$_2$/Ag$_2$S thin film

FIGURE 7. XRD spectra of TiO$_2$/rGO/CuInS$_2$ thin film with Ag$_2$S deposition layers
The crystallite size of TiO$_2$ and Ag$_2$S in TiO$_2$/rGO/CuInS$_2$ was estimated by Scherrer formula (1). From the calculation, $k$ is the shape constant (0.9), $\lambda$ is the wavelength of the X-ray (0.15406 nm), $\beta$ is the FWHM in radians and $\theta$ is the Bragg’s angle in degree. As stated in Table 1, the crystallite size of TiO$_2$ was around ±33.19 nm to ±33.97 nm for both samples. While, the crystallite size of Ag$_2$S in TiO$_2$/rGO/CuInS$_2$ was estimated to be around ±19.26 nm.

$$d = \frac{k\lambda}{\beta \cos \theta}$$ (1)

### TABLE 1. Crystallite size of TiO$_2$ and Ag$_2$S using Scherrer equation

| Sample          | 2θ position (deg.) | FWHM (deg.) | Crystallite size (0.01 nm) |
|-----------------|--------------------|-------------|-----------------------------|
| Without Ag$_2$S | TiO$_2$            | 36.08       | 0.28                        | 33.19                         |
| With Ag$_2$S    | TiO$_2$            | 36.05       | 0.27                        | 33.97                         |
|                 | Ag$_2$S            | 31.52       | 0.48                        | 19.26                         |

### OPTICAL PROPERTIES

The optical spectrum of the thin film TiO$_2$/rGO/CuInS$_2$ with and without Ag$_2$S deposition layers can be observed through UV-VIS Spectroscopy as shown in Figure 8. The significant changes in light absorption can be compared where the absorption of visible light much higher by the QDs structure with the presence of the Ag$_2$S deposition layer. As the light is absorbed by photosensitizer, the result is an increase in the energy content of the QDs structures. A blue-shift was observed in the electronic properties of the QDs CuInS$_2$ with the Ag$_2$S presence. Even though a blue-shift has been typically observed in the literature for shelling of chalcopyrite CuInS$_2$ (Meng et al. 2015), and it results from the compounding on the surface between the QDs material and the Ag$_2$S. Furthermore, a blue-shift can be attributed to the larger particle size of the compound as the Ag$_2$S layer was deposited. In the meantime, a small red-shift in the absorption region was also detected at the visible edge from the UV-VIS spectra.

In this process, the compound formed has a new band gap energy representative of the ratio of the component materials. However, further studies need to be conducted to identify the materials band gap since the current analysis can only be done up to 700 nm wavelength. Supposedly, the particle size can also be the aspect affecting the band gap of the substantial itself. Therefore, the band gap of TiO$_2$/rGO/CuInS$_2$ thin film with Ag$_2$S layers supposed to be narrower than before the Ag$_2$S deposition.

![Figure 8. UV-VIS spectra of TiO$_2$/rGO/CuInS$_2$ thin film with Ag$_2$S deposition layers](image-url)
ELECTRICAL PROPERTIES

Figure 9 shows the semi-circular curves of electrochemical impedance spectra (EIS) that show the interfacial charge-transfer resistances of the cells. The $R_s$ of the electrodes in both samples is in the range of 53.3 - 52.1 $\Omega$ since both samples used identical FTO substrate, TiO$_2$ films, and electrolyte. This shows that passivation layer has no effect to the interface combination between FTO substrate and TiO$_2$ films (Peng et al. 2014).

![Graph showing EIS spectra of TiO$_2$/rGO/CuInS$_2$ thin film with Ag$_2$S deposition layers](image)

However, decrement of semi-circular diameter was observed with the presence of Ag$_2$S layer. The changes should be ascribed to the charge transfer between TiO$_2$/QDs interface and/or QDs/electrolyte interface. From the EIS spectra, it indicates that the charge transfers resistance decreases with passivation deposition layer (Solaiyammal & Murugakoothan 2019). The lifetime of the electrons, $\tau_e = 1/(2\pi f_{\text{max}})$ where $f_{\text{max}}$ is the maximum frequency of the peaks (Tian et al. 2012). The electron lifetime increases with size of the particles as stated in Table 2. According to Ilaiyaraja et al. (2018), due to larger surface defects in smaller sized particles, the electron lifetime might get influenced as well.

| Sample         | $R_s$ (\$\Omega\$) | $R_{\text{ct}}$ (\$k\Omega\$) | $\tau_e$ (ms) |
|----------------|-------------------|-------------------------------|---------------|
| Without Ag$_2$S | 53.3              | 3.03                          | 1.77          |
| With Ag$_2$S   | 52.1              | 2.14                          | 3.43          |

Differences in solar cell structure and material will certainly show different performance. Therefore, it is very significant to compare the value of power conversion efficiency for each sample through the I-V curve. In this study, the solar cells comprised redox couple I/I$_3$ as the electrolyte and Pt glass as the counter electrode with different photo anodes. The I-V curve was measured under simulated sunlight with active area of 0.25 cm$^2$. The performance of the solar cells ($I_{\text{sc}}, I_{\text{oc}}, P_{\text{max}}, \eta$) for both samples were specified in detail in Table 3. The efficiency values of the samples studied can be compared and discussed.
### TABLE 3. Photovoltaic parameters of the assembled TiO$_2$/rGO/CuInS$_2$ and TiO$_2$/rGO/CuInS$_2$/Ag$_2$S solar cells

| Sample          | $V_{oc}$ (V) | $J_{sc}$ (mA cm$^{-2}$) | $FF$ | $\eta$ (%) |
|-----------------|--------------|-------------------------|------|------------|
| Without Ag$_2$S | 0.376        | 0.356                   | 0.55 | 0.074      |
| With Ag$_2$S    | 0.410        | 1.676                   | 0.48 | 0.330      |

As expected, the presence of the Ag$_2$S layer helps in enhance the efficiency of photovoltaic power conversion. From the I-V curve as shown in Figure 10, obvious increment observed for TiO$_2$/rGO/CuInS$_2$ photo anode with Ag$_2$S layers compared to the other sample. Compared to TiO$_2$/rGO/CuInS$_2$ photo anode with Ag$_2$S deposition layers produced higher value of power conversion efficiency, 0.33% with higher value of $I_{sc}$ and $FF$, 0.419 mA and 48%, respectively. It proved that TiO$_2$/rGO/CuInS$_2$/Ag$_2$S have better capability in electrical conductivity and electron mobility than TiO$_2$/rGO/CuInS$_2$. As the result, solar cell performance improved with the presence of the Ag$_2$S deposition layers compared to the sample without the Ag$_2$S passivation layers.

![FIGURE 10. J-V curve of TiO$_2$/rGO/CuInS$_2$ thin film with and without Ag$_2$S deposition layers](image)

### CONCLUSION

Ag$_2$S layers has been successfully deposited onto TiO$_2$/rGO/CuInS$_2$ thin film using SILAR technique. The effect of Ag$_2$S on the photovoltaic performance of rGO/CuInS$_2$ based QDSSCs was investigated. From FESEM images, the average particles size of the samples ranged from ±46.52 to ±53.97 nm in diameter. The XRD results showed peaks at 33.61°, 40.74° and 43.41° of Ag$_2$S structure and the crystallite size of Ag$_2$S was estimated around ±19.26 nm. According to UV-VIS analysis, TiO$_2$/rGO/CuInS$_2$ showed better light absorption capability with the presence of Ag$_2$S layers. Regarding the considerable results obtained, it was pointed out that TiO$_2$/rGO/CuInS$_2$ with Ag$_2$S as passivation layer can be introduced as an effective photo anode for making efficient QDSSC devices with 0.33% of power conversion efficiency. Therefore, for further investigation, other characterizations should be carried out in order to prove the influence of Ag$_2$S layers in enhancement of the rGO/CuInS$_2$ based QDSSCs performance.
ACKNOWLEDGEMENTS

The authors would like to acknowledge the financial assistance provided (Grant No.: 07-01-02-SF1388) by the Ministry of Energy, Science, Technology, Environment and Climate Change (MESTECC). Besides, the authors are thankful to the supports received from Solar Energy Research Institute (SERI) and Center for Research and Instrumentation Management (CRIM), Universiti Kebangsaan Malaysia (UKM).

REFERENCES

Han, M., Jia, J., Yu, L. & Yi, G. 2015. Fabrication and photoelectrochemical characteristics of CuInS₄ and PbS quantum dot co-sensitized TiO₂ nanorod photoelectrodes. RSC Advances 5(64): 51493-51500.

Holi, A.M., Zainal, Z., Talib, Z.A., Lim, H.N., Yap, C.C., Chang, S.K. & Ayal, A.K. 2017. Enhanced photoelectrochemical performance of ZnO nanorod arrays decorated with CdS shell and Ag₂S quantum dots. Superlattices and Microstructures 103(2017): 295-303.

Hosseinpour-Mashkani, S.M., Salavati-Niasari, M. & Mohandes, F. 2014. CuInS₂ nanostuctures: Synthesis, characterization, formation mechanism and solar cell applications. Journal of Industrial and Engineering Chemistry 20(5): 3800-3807.

Ilaiyaraja, P., Rakesh, B., Das, T.K., Mocherla, P.S. & Sudakar, C. 2018. CuInS₂ quantum dot sensitized solar cells with high VOC≥ 0.9 V achieved using microsphere-nanoparticulate TiO₂ composite photoanode. Solar Energy Materials and Solar Cells 178: 208-222.

Kouhnavard, M., Ikeda, S., Ludin, N.A., Khairuddin, N.A., Ghaifari, B.V., Mat-Teridi, M.A., Ibrahim, M.A., Sepeai, S. & Sopian, K. 2014. A review of semiconductor materials as sensitizers for quantum dot-sensitized solar cells. Renewable and Sustainable Energy Reviews 37(2014): 397-407.

Kumari, A., Singh, I., Prasad, N., Dixit, S.K., Rao, P.K., Bhatnagar, P.K., Mathur, P.C., Bhatia, C.S. & Nagpal, S. 2014. Improving the efficiency of a poly(3-hexylthiophene)-CuInS₂ photovoltaic device by incorporating graphene nanopowder. Journal of Nanophotonics 8 (1): 083092.

Madhavan, A.A., Kalluri, S., Chacko, D.K., Arun, T.A., Nagarajan, S., Subramanian, K.R., Nair, A.S., Nair, S.V. & Balakrishnan, A. 2012. Electrical and optical properties of electrospun TiO₂-graphene composite nanofibers and its application as DSSC photo-anodes. RSC Advances 2(33): 13032-13037.

Meng, W., Zhou, X., Qiu, Z., Liu, C., Chen, J. & Yue, W. 2015. Reduced graphene oxide-supported aggregates of CuInS₂ quantum dots as an effective hybrid electron acceptor for polymer-based solar cells. Carbon 96: 532-540.

Mustakim, N.S.M., Ubani, C.A., Sepeai, S., Ludin, N.A., Teridi, M.A.M. & Ibrahim, M.A. 2018. Quantum dots processed by SILAR for solar cell applications. Solar Energy 163(2018): 256-270.

Peng, Z., Liu, Y., Zhao, Y., Chen, K., Cheng, Y., Kovalev, V. & Chen, W. 2014. ZnSe passivation layer for the efficiency enhancement of CuInS₂ quantum dots sensitized solar cells. Journal of Alloys and Compounds 587(2014): 613-617.

Solaiyammal, T. & Murgulakoothan, P. 2019. Green synthesis of Au and the impact of Au on the efficiency of TiO₂ based dye sensitized solar cell. Materials Science for Energy Technologies 2(2): 171-180.

Tian, J., Gao, R., Zhang, Q., Zhang, S., Li, Y., Lan, J., Qu, X. & Cao, G. 2012. Enhanced performance of CdS/CdSe quantum dot cosensitized solar cells via homogeneous distribution of quantum dots in TiO₂ film. The Journal of Physical Chemistry C 116(35): 18655-18662.

Tubtimtai, A., Wu, K.L., Tung, H.Y., Lee, M.W. & Wang, G.J. 2010. Ag₂S quantum dot-sensitized solar cells. Electrochemistry Communications 12(9): 1158-1160.

Ubani, C.A., Ibrahim, M.A., Teridi, M.A.M., Sopian, K., Ali, J. & Chaudhary, K.T. 2016. Application of graphene in dye and quantum dots sensitized solar cell. Solar Energy 137: 531-550.

Yue, W., Lan, M., Zhang, G., Sun, W., Wang, S. & Nie, G. 2014. Size-dependent polymer/CuInS₂ solar cells with tunable synthesis of CuInS₂ quantum dots. Materials Science in Semiconductor Processing 24(2014): 117-125.

Zhang, R., Qi, S., Jia, J., Torre, B., Zeng, H., Wu, H. & Xu, X. 2015a. Size and refinement edge-shape effects of graphene quantum dots on UV-visible absorption. Journal of Alloys and Compounds 623(2015): 186-191.

Zhang, X., Liu, J., Zhang, J., Vlachopoulos, N. & Johansson, E.M. 2015b. ZnO@Ag₂S core-shell nanowire arrays for environmentally friendly solid-state quantum dot-sensitized solar cells with panchromatic light capture and enhanced electron collection. Physical Chemistry Chemical Physics 17(19): 12786-12795.

Nurul Syafiqah Mohamed Mustakim
Spectrum International College of Technology
2F-26A, The Main Place Mall
Jalan USJ21/10, USJ 21
47360 Subang Jaya, Selangor Darul Ehsan
Malaysia

Nurul Syafiqah Mohamed Mustakim, Muhazri Abd Mutalib, Suhaila Sepeai, Norasikin Ahmad Ludin, Mohd Asri Mat Teridi & Mohd Adib Ibrahim*
Solar Energy Research Institute (SERI)
Universiti Kebangsaan Malaysia
43600 UKM Bangi, Selangor Darul Ehsan
Malaysia

*Corresponding author; email: mdadib@ukm.edu.my

Received: 12 August 2020
Accepted: 27 August 2020