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High-Performance solar-blind flexible Deep-UV photodetectors based on quantum dots synthesized by femtosecond-laser ablation

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High-performance deep ultraviolet (DUV) photodetectors operating at ambient conditions with < 280 nm detection wavelengths are in high demand because of their potential applications in diverse fields. We demonstrate for the first time, high-performance flexible DUV photodetectors operating at ambient conditions based on quantum dots (QDs) synthesized by femtosecond-laser ablation in liquid (FLAL) technique. Our method is facile without complex chemical procedures, which allows large-scale cost-effective devices. This synthesis method is demonstrated to produce highly stable and reproducible ZnO QDs from zinc nitride target (Zn$_3$N$_2$) without any material degradation due to water and oxygen molecule species, allowing photodetectors operate at ambient conditions. Carbon-doped ZnO QD-based photodetector is capable of detecting efficiently in the DUV spectral region, down to 224 nm, and exhibits high photo responsivity and stability. As fast response of DUV photodetector remains significant parameter for high-speed
communication; we show fast-response QD-based DUV photodetector. Such surfactant-free synthesis by FLAL can lead to commercially available high-performance low-cost optoelectronic devices based on nanostructures for large scale applications.

**Graphical abstract**

Keywords: Deep-ultraviolet (DUV), Femtosecond-laser ablation in liquid, Flexible photodetector, Quantum dots (QDs), ZnO, zinc nitride.
1. Introduction

Modern optoelectronic technologies require cost-effective, energy efficient and transparent devices fabricated on flexible substrates. Deep-ultraviolet (DUV)-based optoelectronic devices, such as photodetector and sensor devices operating in the UV-C spectral region (< 280 nm), are among these important technologies that have drawn considerable attention due to their potential applications, including high-temperature flame and missile launch detection, environmental monitoring, imaging techniques, chemical analysis, ozone monitoring, space-to-space communications, and biological threat detection. [1-4] Although performance enhancement in UV-A and UV-B photodetectors has been achieved, performance of the devices operating in the UV-C range remains inferior, due to much lower photo-generated carrier density. [5-8] The technology operating in the UV-C range is still facing many challenges. Commercially available silicon-based photodetectors require high-temperature processing and suffer from surface recombination due to strong light absorption in the DUV range. [4-8] Conventional thin film-based DUV photodetectors suffer from lattice mismatch between the substrates and the films, which hinders performance and long-term stability. [3,5-8] This complicates the logistics of large-scale manufacture, invariably leading to a prohibitively expensive end product. Therefore, to address these issues and accomplish the breakthrough technology requirements in the UV-C range, wide-bandgap quantum dot (QD) materials have attracted intense interest of the scientific community. QD structures possess ultra-high surface-to-volume ratio that significantly enhances the photo-generated carrier density and detection sensitivity in the UV-C range compared to other nanostructures. In particular, fabrication of solution-processed QD-based devices is cost-effective and can be achieved using flexible substrates, thus meeting the growing demand for flexible electronics and optoelectronics that are immune to stress and strain. [9,10] However, due to the water and oxygen molecule species defects that trap the carriers in most nanostructure-
based devices, the device performance deteriorates further even in controlled environments (e.g., vacuum).[11-13]. Therefore, high-quality solution-processed QDs as an active layer suitable for highly responsive and reproducible DUV photodetectors operating in ambient conditions for large-scale practical applications have not yet been produced. Thus, there is a significant need to find a cost-effective synthesis method for producing solution-processed QDs aimed at DUV optoelectronic devices operating in ambient conditions.

ZnO remains the most promising material in the development of UV optoelectronic devices, due to its wide bandgap (3.3 eV) and high exciton binding energy (60 meV). ZnO possesses high chemical and thermal stability and is naturally abundant and nontoxic. ZnO QDs are particularly interesting, owing to their tunable bandgap in the DUV regime. Furthermore, it is well known that the inherent junction barrier between ZnO QDs is highly sensitive to the concentration of photo-generated carriers. Thus, dot-dot junctions in a ZnO QD network should significantly improve conductance under DUV illumination. [14-16]

In this work, we report on a cost-effective, facile and simple femtosecond laser ablation (FLAL) synthesis method that can be used to fabricate a novel UV-C fixable photodetectors based on QDs solely as an active layer, operating at ambient condition. We show for the first time that high-quality, stable and conductive C-doped ZnO QDs can be successfully synthesized from zinc nitride (Zn,N) targets. We show that solution-processed ZnO QDs acting as an active layer can be used in fabricating state-of-the-art flexible UV-C devices as a proof-of-concept application, operating in ambient conditions as our QDs are not affected by water and oxygen molecular degradation. High responsivity, fast response and stable switching performance of DUV photodetectors in the UV-C range are also demonstrated. The formation mechanism is
explicated with the support of experimental results and theoretical calculations using density functional theory (DFT).

2. Materials and Methods

2.1 FLAL QD Synthesis

In our simple synthesis method, we used a titanium-sapphire (coherent-Mira 900) femtosecond (fs) laser with optimum operating conditions of 150 fs pulse width and 76 MHz pulse repetition rate at 800 nm wavelength.

2.2 Material characterizations

High-resolution transmission electron microscopy (HR-TEM) measurements (using Titan 60-300 microscope, from FEI Co, equipped with Cs probe corrector and Quantum 966 imaging filter) were carried out to investigate the structural properties of our FLAL-synthesized QDs. Electron energy-loss spectroscopy (EELS) and energy-dispersive x-ray (EDX) maps were performed by titan TEM system to confirm the material composition, whereas x-ray photoelectron spectroscopy (XPS) (Kratos AXIS supra) was performed to confirm the chemical states of the doped atoms. Room temperature absorption measurements were achieved using UV-VIS Varian Cary 5000 spectrophotometry. All Raman measurements were performed using WiTec Raman system, equipped with 532 nm laser source, 100× objective, and 600 lines/mm grating.

2.3 Device fabrication

Interdigitated electrodes were prepared using photolithography on silicon oxide substrate (SiO2) followed by e-beam evaporation (Oxford Instruments, UK) of titanium for Device 1 and Device 2. For Device 3 (flexible polyethylene terephthalate [PET] substrate), we used the shadow-mask technique based on the electron-beam (e-beam) evaporation. The Ti electrode
thickness remained at 100 nm, and the distance between the electrodes was 20 µm. Device 1 was
prepared by drop casting 10 ml of colloidal QD solution over time, while keeping the substrate
temperature constant at 100 °C. Device 2 was prepared by spray coating 10 ml of colloidal QD
solution on a heated (100 °C) substrate, whereas Device 3 (flexible) was prepared by spray
coating 10 ml of colloidal QD solution on an interdigitated titanium (Ti) electrode (ITD)
deposited on a PET substrate. More specifically, while the PET substrate was kept on a hotplate
at 50 °C, a small volume of the solution, such as 2 ml, was sprayed on its surface for a precise
amount of time (5 min).

2.4 DFT calculations

We simulated a “magic” Zn_{12}O_{12} cluster (shown in Figure 3a) by employing the Vienna
Ab initio Simulation Package (VASP), a plane wave electronic structure code.[17,18] The
selection of this cluster was based on reports indicating that this particular size possesses the
most stable structure, and is hence named the “magic” cluster.[19] To avoid interactions between
the repeating images due to periodicity, the cluster was simulated in a cube with 20 Å side length
that ensured sufficient separation. We used PAW-PBE formalism [20] to describe the exchange
and a correlation functional in the generalized gradient approximation with the Hubbard
parameters U = 4.0 eV and J = 1.0 eV. [21] The calculations were performed at the gamma point,
and a plane-wave cutoff energy of 500 eV was used to describe the basis set. We optimized the
cluster within a force tolerance of 0.01 eV/Å to minimize the Hellmann-Feynman forces on each
atom.

2.5 Device characterizations

A HeAg pulsed laser (Laser 2000 UK Ltd.) with the wavelength of 224.3 nm was used
for illumination. The laser repetition rate remained at 1 Hz throughout the experiments. To
measure the I−V characteristics, a probe station was attached to a Keithley 2400 Source Meter (Tektronix, China). The laser pulse width remained below 200 µs. The responsivity (R) was calculated by dividing the generated photocurrent (I_{ph}) by the illuminated optical power on the effective area (P_o):

\[ R = \frac{I_{ph}}{P_o} \]

(1)

3. Results and Discussion

Our FLAL synthesis method has several advantages over chemical methods. Different chemical, hydrothermal and electrodeposition methods have been used for the synthesis of ZnO nanostructures, most of which involved complex procedures, sophisticated instruments and rigid experimental conditions.[22-28] Chemical methods involve organic solvent (e.g., DMF), as well as reducing and capping agents. Therefore, byproducts of chemical and electrochemical processes must be managed safely, while post-synthesis procedures are required to collect the nanoparticles or nanostructures.[29-30] Moreover, a post-annealing process for crystallization in a reducing or oxidizing atmosphere is necessary in the preparation process, which usually destroys the as-prepared nanostructures.[30] Therefore, an alternative technique is still required to facilitate the production of high quality and stable QDs for practical high-performance devices. In response to this need, we developed a simple FLAL synthesis process that can be carried out under atmospheric conditions. In contrast to the chemical methods, the FLAL method is a simple, fast, versatile and inexpensive means of producing high-quality solution-processed C-doped ZnO QDs. The ultrafast pulses of fs lasers do not affect the material absorption properties and do not interact with ejected species and expanding plasma plumes. [31,32] Any secondary (post-ablation) effects on the QDs can thus be avoided. [30-32] Therefore, the incident
ultrafast pulses should mostly interact with the target surface, resulting in highly efficient material ablation. In addition, in FLAL, the fs pulse duration is shorter than the time scale of electron coupling (in the ps range) and thermal damage due to ablation is low relative to continuous wave (CW) or nanosecond (ns) laser ablation. [31,32] Therefore, this FLAL method is classified as a melt-free ablation process, if carried out close to the ablation threshold. [31,32] We found that FLAL is non-selective to the source material, which allows synthesizing many other materials. Most importantly, it can also be scaled up for higher throughput practical device fabrication.

Here, as we used Zn$_3$N$_2$ target as a source material for ZnO, we confirm that such target is the best source material for producing high-quality conductive ZnO QDs because it requires far less laser power for FLAL synthesis compared to pure ZnO target. In addition, Zn$_3$N$_2$ target also permits carbon (C) corporation into ZnO QDs to increase photo-generated carriers. Furthermore, no ZnO nanoparticles were produced by ZnO target using similar laser conditions. We attribute the difference in the ablation laser power threshold for the targets to the bond strength between Zn and N or O. The primary material for ablation was a Zn$_3$N$_2$ target and the ablation was carried out in an ethanol solution. It is known that Zn$_3$N$_2$ is not a particularly stable compound, especially in a liquid medium. [33,34] Therefore, the C dopant is incorporated into the QD crystal structure during the ablation process. The N atoms in the Zn$_3$N$_2$ structure that remain unstable are easily replaced by O to form ZnO hexagonal crystals. At the same time, plenty of C is available during ablation because the laser breaks down the ethanol compound, releasing free radicals and incorporating C as a dopant into the QD structure.
Figure 1. Titan 60-300 microscope, obtained from FEI Co, equipped with Cs probe corrector and imaging filter Quantum 966, operated at 200 kV in STEM mode was used. (a) TEM image of ZnO QDs. (b) TEM image of ZnO QDs exhibiting typical fringes of crystalline structures. (c) Average particle diameter (3.4±1.7 nm) as measured in several low-resolution images. EELS compositional maps of QDs of (d) O, (e) Zn and (f) C. (g) EDX measurements of the ZnO QDs confirming the presence of C, Zn and O. (The Cu signal is produced by the TEM grid).
The HR-TEM image in Figure 1a shows the crystallinity (wurtzite structure) of QDs. The d-spacing of ~0.28 nm corresponds to the (100) plane, as shown in Figure 2b. [35] To calculate the size distribution of the ablated QDs, we measured the diameter of ~100 QDs in a low-magnification image. The size distribution shown in Figure 1c indicates an average particle diameter of 3.4±1.7 nm. Figure 1d-1f show the EELS elemental composition maps of the QDs, indicating that the ZnO QDs are composed of Zn and O, with significant presence of C dopants. The EDX spectroscopy confirms the heavy C doping in ZnO QDs, as shown in Figure 1g. While C atoms can occupy both Zn-vacancy (V_{Zn}) and O-vacancy (V_o) sites, C dopants were found to prefer substitutional V_o sites in ZnO structures. [36] The substitutional defects depend on the synthesis process.

We further confirm the C incorporation into ZnO QDs by XPS. Figure 2a shows the C 1s core-level spectrum, indicating a broad asymmetric peak that is fitted by a Gaussian function (as it provided the best fit to the data), which is de-convoluted into four peaks. The asymmetric behavior of the peak implies presence of more than one chemical state of C. The lower binding energy peaks at 284.73 eV and 283.41 eV are attributed to pure graphitic C contamination and Zn−C−V_o bonding, respectively. [37,38] This result shows the presence of C atoms in carbide form, indicating that C dopants occupy the substitutional anion sites and facilitate formation of Zn−C bonds in the C-doped ZnO QDs.[38] The higher binding energy peaks at 285.75 eV and 288.59 eV are attributed to the Zn−O−C bond and the absorption of the C=O on the surface, respectively. [37,38] The deconvolution of the O 1s peak in Figure 2b reveals binding energies at 529.89 eV and 531.07 eV, which respectively correspond to the Zn−O bond and surface adsorption of −OH functional group. [43,44] The incorporation of −OH group into the surface of the QDs is confirmed by Fourier transform infrared spectroscopy (FTIR) measurements, as shown in Figure S1 (Supporting Information). In addition, Raman spectrum of the QDs reveals
clear contributions of C–H vibration and C-clusters, as shown in Figure S2 (Supporting Information). TEM and XPS results are also supported by the Raman results pertaining to C-doped ZnO QDs, as shown in Figure S2, indicating wurtzite ZnO structure along with the presence of C, which is also indicative of nanocomposite structure. Our analysis demonstrates that high-quality ZnO QDs doped with C can be successfully prepared by FLAL synthesis from a Zn$_3$N$_2$ target material.

**Figure 2.** Core-level XPS spectra. (a) High-resolution XPS C 1s spectrum and (b) O 1s spectrum of the C-doped ZnO QD samples.

To elucidate the role played by C atoms in stabilizing QDs by engineering the QD band structure, which allows generating more photo-carriers compared to undoped ZnO QDs, we conducted a density functional theory (DFT) study. Figure 3a shows a “magic” ZnO cluster (Zn$_{12}$O$_{12}$) with a hexagonal structure corresponding to the structure of ZnO QDs. Here, we consider three scenarios to gain insight into the energetics of the point defect formation in the cluster, namely (i) an O vacancy ($V_O$), (ii) a carbon substituted to the O site ($C_O$), and (iii) a ($V_O+C_O$) complex. We optimized the cluster for each case and calculated the formation energy ($E_f$) using the following equation
where the first term \( (E(D)) \) represents the total energy of the cluster containing defects, the second term \( (E(R)) \) denotes the total energy of the reference cluster without defects, and \( n_i \) and \( \mu_i \) are respectively the number and chemical potential of the defects that are added (-\( n_i \)) or removed (+\( n_i \)) from the cluster. The chemical potential is estimated as the energy per atom of the element in the most stable structure, in this case, bulk Zn or molecular C and O. The effect of charge states was not considered in the calculation of \( E' \), as no charged defects were added to the clusters. We observe that the substitutional C (\( E' = 2.92 \) eV) is a preferable defect compared to \( V_o \) (\( E' = 5.40 \) eV), as shown in Figure 3b. Interestingly, the presence of C in the ZnO cluster facilitates the formation of \( V_o \), creating a C−V_o complex in the QD structure as \( E' \) is reduced from 2.92 eV to 1.88 eV by introducing \( V_o \) in the vicinity of C in the Zn−C−V_o bonding configuration, which substantiates the XPS results.

We also calculated the density of states (DOS) of the Zn_{12}O_{12} (pristine ZnO) and Zn_{12}O_{10}C_1 (ZnO doped with the C−V_o complex) clusters for a qualitative comparison with the experimental results. The DOS of the Zn_{12}O_{12} cluster (pure ZnO) shows that the \( p \) states of Zn and O are prominent and are located near the Fermi level (\( E_F \)), while the Zn \( d \) state occurs deep inside the valence band, as shown in Figure 3c. Due to the presence of C−V_o complex in ZnO QDs, the \( Cp \) states appear near \( E_F \), signifying the probability of hybridization of the O and Zn \( p \) states, as shown in Figure 3d. Remarkably, the Zn \( d \) states and C \( s \) states are shown at the same energy levels, resulting in a strong \( s−d \) hybridization, which leads to a strong Zn−C bond, while also strengthening the stabilization of the C+V_o defect complex in the cluster.
Figure 3. (a) The optimized Zn$_{12}$O$_{12}$ cluster. The grey and red spheres indicate Zn and O atoms, respectively. (b) The formation energy of defects ($E'$) in Zn$_{12}$O$_{12}$ cluster. (c) The density of states (DOS) of a Zn$_{12}$O$_{12}$ (corresponding to pure ZnO QDs) and (d) Zn$_{12}$O$_{10}$C$_1$ (corresponding to C-doped ZnO QDs with the presence of V$_o$ defects) clusters.

As ZnO is intrinsically an n-type semiconductor, its Fermi level can be engineered by doping the structure with C. [39] Tan et al. [39] reported on the C-doped ZnO films with high Hall mobility and hole concentrations. Cho et al. [40] demonstrated that incorporation of C into ZnO reduces the likelihood of recombination, thereby enhancing photo-current generation. Consequently, C-doped nanostructures have been used in photocatalysis. [38,40] We, therefore,
in ZnO QDs, C doping would indirectly influence photodetector device performance. While, thus far, C-doped ZnO QDs have not been prepared by chemical synthesis, several attempts have been made to produce low-quality C-doped ZnO nanostructures to increase the carrier density by thermal plasma and chemical techniques. Thus, we demonstrate high-quality C-doped ZnO QDs synthesized by FLAL that can be employed for development of a wide range of devices.

**Figure 4.** (a) Absorption spectra of QDs in ethanol over days of aging. (b) Tauc plot of the direct band gap of as-prepared QDs and after aging for six days in ethanol. Inset shows the shoulder peak that emerges in the spectrum after ageing.

We performed absorption spectroscopy measurements to investigate the change in the bandgap due to the change in the surface states (surface passivation over time), as shown in Figure 4. Optical absorption spectra were acquired from the colloidal solution of the QDs in ethanol. Figure 4a shows the absorption spectra of the colloidal QDs obtained over several days of ageing in ethanol. The spectrum of as-prepared sample does not show a pronounced absorption edge at the bulk ZnO bandgap of 3.64 eV. The measured bandgap energy is observed at 4.9 eV, as shown in Figure 4b. However, after ageing in ethanol, a shoulder peak (at 3.64 eV) related to ZnO bulk appears, as evident in the Tauc plot in Figure 4b. This shoulder peak is
attributed to the surface oxidation of the QDs. The as-prepared sample exhibits higher absorption in the visible region compared to the aged samples. This high absorption is due to O deficiency in the core of the as-prepared QDs and the presence of C doping. However, the oxidation process leads to passivation, which resulted in a blueshift in the absorption edge of the aged samples during the investigated period. The passivation process on the surface of the QDs completely stabilized after six days, and no significant changes in the optical properties were observed for many months after that. The absorption results indicate superior stability and surface passivation of the QDs in colloidal form. Moreover, as a sharp absorption edge appears in the DUV (UV-C) regime, this finding implies that C-doped ZnO QDs are suitable candidates for UV-C detection, depending on their electrical properties. We determine the average size of the QDs based on the absorption measurements, which is close to the value obtained through TEM (Supporting Information, S3).

The schematic in Figure 5a provides the steps and the method of device preparation. Figure 5b shows the transient photoresponse of Device 1 operating under ambient conditions (prepared by drop-casting method on SiO$_2$ substrate) under pulsed UV-C illumination (224.3 nm) at different bias voltages. The current-voltage (I-V) characteristics is shown in Figure S6 (Supporting Information), indicating semi-ohmic behavior under DUV illumination. The laser excitation of the photodetector at 5.5 eV is well above the 4.9 eV QD bandgap. Under pulsed laser illumination, at bias voltages of 1 V, 2 V and 5 V, the device exhibits a stable response over time. At higher bias voltages, the device starts to exhibit unstable responses, as shown in Figure S3 (Supporting Information). The instability of the photoresponse at higher bias voltages can be attributed to the unstable Schottky junction between the QDs and the metal electrodes. Device 1 works optimally in the 2–5 V range due to its very high responsivity (up to 100 mA/W), indicating significant stability in this voltage regime.
Figure 5. (a) (upper panel) Schematic illustration of FLAL synthesis with QDs coated on the interdigitated titanium electrode on rigid and flexible substrates. (Lower panel) Photodetector devices are exposed to a 224.3 nm HeAg pulsed laser under ambient conditions. The repetition rate of the laser pulse with a pulse width of 200 µs remained constant at 1 Hz throughout the photodetector measurements. (b) The transient photo-response of Device 1 (SiO₂) at different bias voltages. (c) The responsivity (left axis) and the decay time (right axis) of Device 1 as functions of bias voltage.
Figure 6. (a) Transient photocurrent generation under DUV illumination for Device 2 (on rigid substrate with the airbrush spray-coating technique) at ambient conditions. The average responsivity is $295 \pm 4$ mA/W at 5 V bias voltage. (b) Transient photocurrent generation under DUV illumination for Device 3 (flexible PET substrate with the airbrush spray-coating technique). The average responsivity is $88.4 \pm 0.7$ mA/W at 5 V bias. (c) Responsivity measurement of Device 3 as a function of the number of bending cycles. The inset photos show Device 3 bending degree. (d) Photocurrent generation following different numbers of bending cycles at angle.

To optimize the device response, airbrush spray-coating technique was used for fabricating Device 2 (SiO$_2$ substrate) and Device 3 (flexible substrate), as this is a simple and
cost-effective device fabrication method and is more effective than drop casting. Figure 6a shows the photocurrent generation of Device 2 (operating under ambient conditions), with an average responsivity of 295±4 mA/W, which is higher than that of Device 1. The transient photoresponse of Device 3 is shown in Figure 6b, indicating responsivity of 88.4 mA/W. The responsivity values of the three devices are the highest achieved to date for DUV photodetectors based on solution-processed QD solely as an active layer. Moreover, they are superior to those of commercial state-of-the-art UV photodetectors. [13,41,42] We exposed Device 2 to DUV light (224 nm) for ~3,500 s to demonstrate their stability and durability. As shown in Figure S7 in Supporting Information, as expected, no significant changes were observed in the photocurrent, indicating robust QDs for DUV devices and high-stability devices for DUV exposure.

Figure 6c shows the responsivity of the flexible device (Device 3) after 150 bending cycles at a certain angle (up to 30°) (the photographs in Figure 6c show the bending setup used for this measurement), indicating that Device 3 is immune to stress and its performance is not affected by the bending process. Figure 6d shows the transient photoresponse as a function of the number of bending cycles, which further confirms that photocurrent generation remains unchanged after even 150 cycles of bending. These results demonstrate the excellent photoelectrical stability of this QD-based flexible DUV photodetector device.

In most photo-detecting and sensing applications, photodetector operation speed is critical. [1,3] Therefore, response time is another key parameter characterizing photodetector devices, as it determines their capability to detect rapidly varying optical signals. A slow temporal response of a photodetector is attributed to high density of trapped electronic states, which is normally induced by defects, as observed in some film- and nanostructure-based photodetectors. [3,43-47] This slow response hinders the practical application of such devices.
Therefore, it is essential to develop photodetector devices with high responsivity and fast response. Figure 5c presents a comparison of the decay time and the responsivity of Device 1 at different voltages. The decay time at 1 V bias voltage has a double exponential response with fast (37.58 ms) and slow (230 ms) components. The decay time for the bias voltages above 1 V has a single exponential response. To calculate the photoresponse time during the rise and decay, the best data fitting for the experimental findings was adopted to measure the decay time, which is in line with that used by other authors.[46-51] The detailed fitting procedure of the rise time and the decay time is shown in Figure S4 (Supporting Information). For Device 2 and Device 3, the response time (rise time and decay time) is shorter than 85 ms in the 2–5 V range.

As visible blindness characteristics are crucial in DUV photodetectors, we have shown the responsivity dependence on the wavelength in Figure S5 (Supporting Information). The Device 2 response drastically declines at wavelengths above 260 nm and the responsivity ratio at 224 nm and 300 nm remains \( R (\lambda=224) \approx R (\lambda=300) \sim 11 \). Therefore, these devices particularly respond to the wavelengths in the UV-C region and exhibit very good solar blindness properties.

**Conclusion**

We reported on the first FLAL synthesis of solution-processed high quality C-ZnO QDs using \( \text{Zn}_2\text{N}_3 \) target and the fabrication of a novel high-performance flexible UV-C photodetector under ambient conditions without any degradation due to water and oxygen molecule species. The synthesis and the fabrication processes are highly reproducible, resulting in high-quality stable QDs. This synthesis method can be applied to other materials intended for a wide range of optoelectronic and electronic applications. We also reported the highest responsivity for DUV photodetectors fabricated by the solution-processed method. The flexible substrate device exhibits immunity to stress, with extremely stable and reproducible responses in the bending
tests. Overall, our work offers the possibility for commercially producing highly stable flexible devices and sensors with high responsivity and fast response times, which can be fabricated using simple and cost-effective techniques that can be industrially upscaled.

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Vitae

Dr Somak Mitra is working as a postdoctoral research fellow at King Abduallah University of Science and Technology (KAUST), Saudi Arabia. He received a Ph.D. degree in 2014 from University of Ulster. Prior to PhD he completed MSc in Photonics (Erasmus Mundus) in 2010. Somak’s expertise is in Nanomaterials-based optoelectronic devices and ultrafast spectroscopy.

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Dr Gobind Das is working as a Research scientist at KAUST. He pursued his Master of Science (Physics) and Master of Technology (Laser Science and Applications) from BHU, Varanasi, India and DAVV, India. Later on, he joined Università degli studi di Trento, Trento for his Ph.D. (Physics). He had wide experience at Universities as a post-doc and in spin-off company, Catanzaro. He carried out his post-doc tenure at Faculty of engineering, University of Trento,
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Mr Kalaivanan Loganathan obtained MSc in Nanoscience and technology, from Pondicherry University, Puducherry, India. During his master’s degree, he joined Dr Roqan’s group at KAUST as an intern to carry out the project of his master’s thesis.
Professor Di Fabrizio conducts interdisciplinary research between physics and biology and nanomedicine that includes basic and applied research in nanotechnology. At KAUST, he is dedicated to setting up a new lab for molecular sensing and imaging. His main interests concern the study of material and macromolecules at nanoscale and their structure and function through novel spectroscopy approaches mediated by nanostructures. His research interests also include nanofabrication of plasmonic devices, optical tweezers-based microscopy Raman spectroscopy for single-molecule detection through scanning probe, design and fabrication of microfluidics nanodevices dedicated to cellomics and drug delivery, proteomics, biophotonic and TEM imaging.

Professor Iman Roqan is a founding faculty member at KAUST. At KAUST, she heads the Semiconductor and Material Spectroscopy Group. Dr. Roqan’s research focuses on semiconductors for optoelectronic devices. Mainly, her work interest is wide-band-gap semiconductor nanostructures for light emitting devices and photodetectors, operating in the UV and visible range. Dr Roqan’s specialty is advanced ultrafast material spectroscopy. She has developed several fabrication methods to improve the functionality of these materials. She obtained her M.Sc. in optoelectronic and photonic devices from St. Andrews and Heriot-Watt Universities, United Kingdom. Her PhD was obtained from the University of Strathclyde, United Kingdom.
Highlights

- The report on DUV photodetector fabrication method using simple, cost-effective and sustainable techniques which is based on solution-processed QDs as an active material, operating at ambient conditions that has not been achieved yet.
- A flexible solution-processed DUV photodetector is demonstrated, with the highest responsivity and stability achieved to date (including commercial devices).
- We show that the method produces highly stable and reproducible QDs as an active material for any devices and can be industrially upscaled.
- The description of the synthesis of carbon doped ZnO QDs from zinc nitride target by femtosecond laser ablation (FLAL).
- Structural, optical and electrical characterizations are described in details.