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Recent developments in deep-ultraviolet sterilization of human respiratory RNA viruses

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Deep-ultraviolet (DUV) sterilization technology using DUV-LEDs has attracted considerable attention owing to its portability, eco-friendliness, high potency, and broad-spectrum sterilization. This study compiles the developments of recent DUV sterilization research. Recent works have investigated DUV sterilization from the perspective of device improvement and principle investigation: one employed a novel epitaxial structure to optimize the performance and fabrication cost of DUV-LEDs and realized potent virus disinfection effects for various respiratory RNA viruses, and another work explained the disinfection phenomenon of SARS-CoV-2 and its variants (Delta and Omicron) in a cryogenic environment. These studies have contributed significantly to the development of DUV sterilization.

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Deep-ultraviolet (DUV) photonics is an effective sterilization technology that damages the genomes of human respiratory RNA viruses[1]. Mercury lamps are conventionally used as DUV light sources for sterilization. However, since the introduction of the Minamata Convention on Mercury in 2020, the manufacture, import, and export of a myriad of products containing mercury have been prohibited. Therefore, AlGaN-based DUV-LEDs, with the advantages of being pollution-free, small, energy-conserving, and having a tunable wavelength, are a perfect alternative to mercury lamps for DUV sterilization[2].

DUV sterilization technology has been widely studied for the inactivation of human respiratory RNA viruses. However, many obstacles remain in the development of DUV sterilization with DUV-LEDs, which can be divided into three groups. First, fabricating DUV-LEDs on high-temperature-annealed (HTA) AlN/sapphire templates introduces strong compressive stress (SCS) and deteriorates their external quantum efficiency (EQE), whereas fabricating DUV-LEDs using AlN single-crystal substrate is too expensive for industrial application; thus, the luminous efficiency and fabrication cost of high-power DUV-LED light sources require further optimization[3,4]. Second, the differences in the virucidal efficacy of DUV on SARS-CoV-2 and its variants (Delta and Omicron) under the same dose is unknown[5]. Third, the principle of the lethal effect of DUV on SARS-CoV-2 and its variants in a cryogenic environment (e.g., food cold chain logistics and outside in winter) has not been clearly demonstrated[6].

To relax the SCS in DUV-LEDs grown on HTA

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AlN/sapphire templates, Li et al.[1] proposed a novel epitaxial structure of DUV-LEDs with AlN/AlGaN superlattices (SLs); the structure diagram is shown in Fig. 1(a). The X-ray diffraction reciprocal space mapping (XRD-RSM) of DUV-LEDs without and with SLs are shown in Fig. 1(b–c), respectively, indicating that the wafer with SLs has a relaxation ratio of ~60%. Moreover, to determine whether the inactivation effect of DUV-LEDs differs between virus mutations, pseudotyped SARS-CoV-2 viruses with different mutated spike proteins on their surfaces were used for the irradiation assay. Figure 1(d) indicates that the inactivation effects of 256 nm LEDs are not disrupted by changes in viral outer membrane proteins. These results contribute to the development of advanced DUV-LEDs for the disinfection of viruses.

To clarify the influence of SARS-CoV-2 and its variants on DUV virucidal efficacy, the effect of DUV disinfection on the Omicron variant was analyzed by Kang et al.[6] They attributed the differences to two possibilities: gene sequence (Fig. 2(a)) and protein composition (Fig. 2(b)). Figure 2(a) shows the inactivation of (+) single-stranded RNA viruses mainly caused by the formation of uracil/uracil (UU) and uracil/cytosine (UC) dimers after UV radiation, and the final DUV intensity radiated on the viral RNA chains affected by proteins is indicated in Fig. 2(b). In addition, the difference in the extinction coefficient (k) of Omicron affects the absorption and reflectivity for DUV radiation. These factors make Omicron significantly different from other strains.

Investigations on the influence of temperature on DUV disinfection are essential for DUV applications in cold conditions. Junyong Kang and his colleagues proposed a negative-U large-relaxation model to demonstrate the DUV disinfection process[6]. A comparison between the low- and high-temperature situations (low or high are relative) is displayed in Fig. 2(c). These results suggest that a cryogenic environment attenuates the lethal effects of DUV radiation.

These studies contribute to the development of portable, long-lasting, and broad-spectrum DUV-LED sterilization applications for disinfecting human respiratory RNA viruses, fill the research gaps regarding the differences in SARS-CoV-2 and its variants (Delta and Omicron), and clarify the influences of the cryogenic environment on DUV virucidal efficacy. Future work could research new types of DUV light sources, such as high-density GaN/AlN quantum dots or directional high-efficiency nanowire LEDs, and investigate the principle of surface roughness or nanoparticle size for DUV sterilization[7].

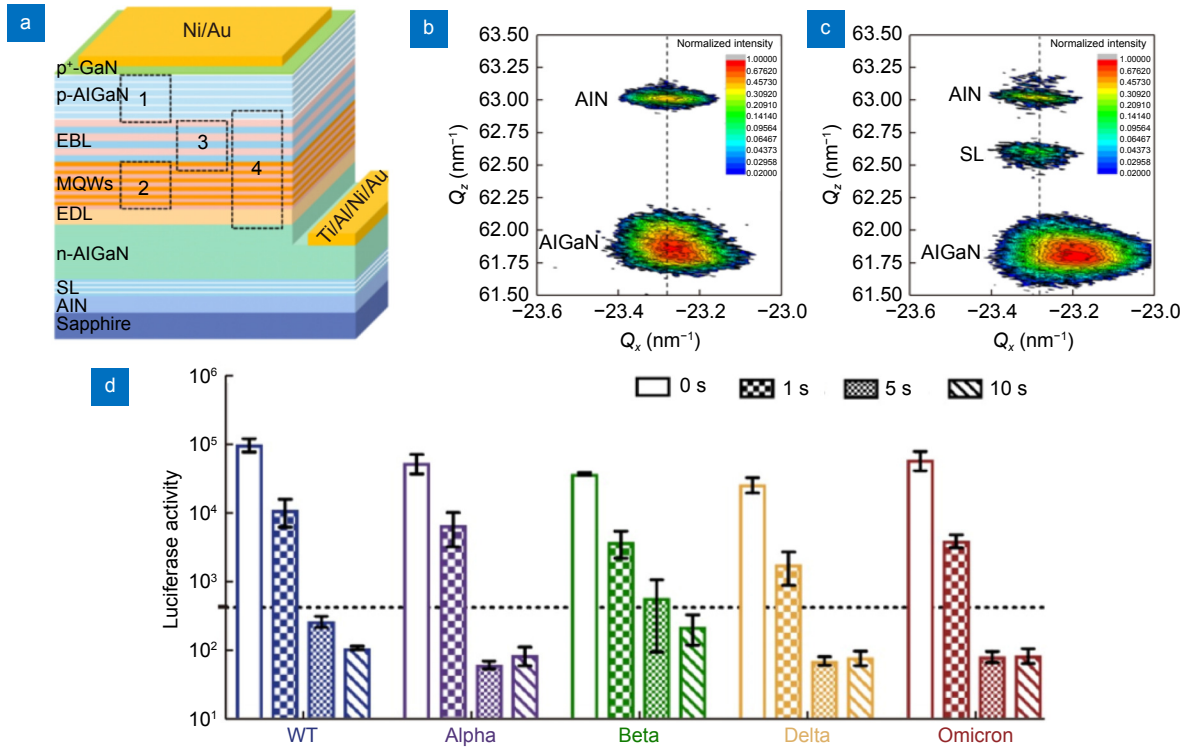

Fig. 1 | (**a**) Structure diagram of DUV-LED with SLs. (**b–c**) XRD-RSMs of the (−105) planes for wafers without and with SLs, respectively. (**d**) Inactivation effects of 256-nm DUV-LED for different SARS-CoV-2 variants.[1]

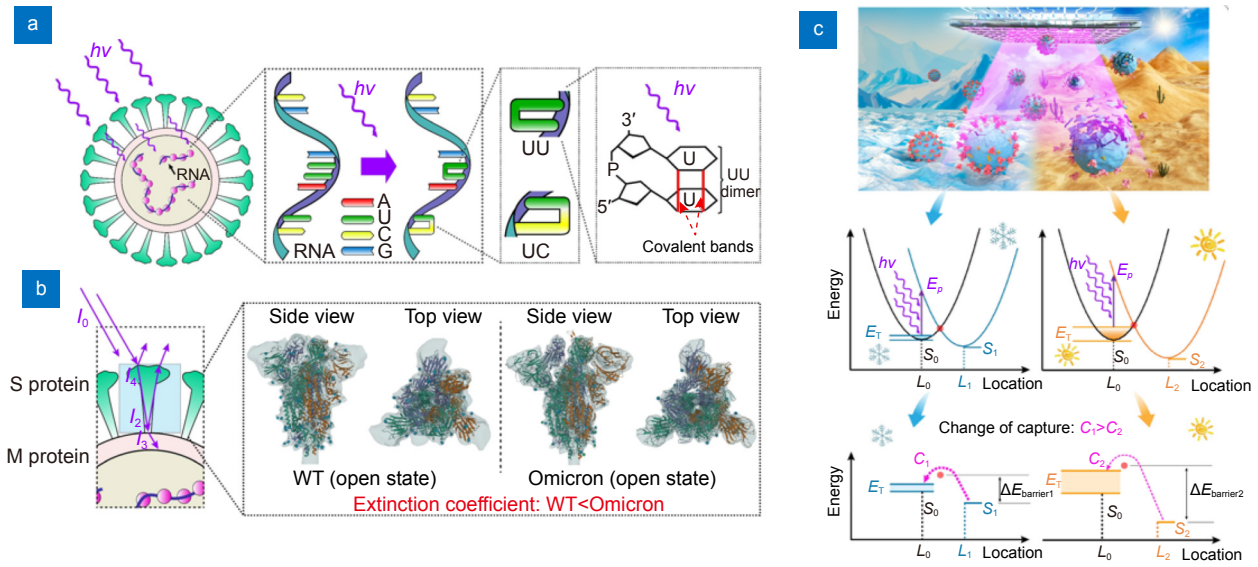

Fig. 2 | (**a**) Influence of Omicron variant on DUV disinfection on (a) gene sequence and (**b**) proteins. (**c**) Influence of low- (left) and high-temperatures (right) on DUV disinfection.[6]

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