Using Photonics to Detect COVID-19-Virus

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Photonics techniques are the science of energy generating, detecting, and transmitting information using light, applying it in every part of life, from microscopy to optical communications. Likewise, it includes cutting-edge applications of lasers, optics, fiber optics, and electro-optical systems in a wide variety of areas of technology, including engineering, healthcare, telecommunications, environmental control, national security, aerospace, and solid-state illumination. As a result, this technique has opened up new challenges in different fields.

Keywords: photonics ; COVID-19 ; laser diagnosis techniques ; optical biosensor ; coronavirus ; light–matter interaction

1. Introduction

The sudden and rapid emergence of severe acute respiratory syndrome coronavirus 2 (SARS-COV-2) caused the novel coronavirus disease (COVID-19). Growing global business and travel are considered the cause of frequent and rapid propagation of infectious diseases worldwide. Correspondingly, faster and on-site diagnosis decisions have also contributed to reducing the spreading of the virus and pandemic disease transmission [1][2], which has a 2–7-day incubation duration before infection initiation. This period is primarily asymptomatic and contagious, as the virus spreads from infected to healthy individuals [3].

Photonics techniques are the science of energy generating, detecting, and transmitting information using light, applying it in every part of life, from microscopy to optical communications. Many solutions have been discovered and created by optical engineering in photonic systems when faced with global pandemic threats [4][5][6][7]. Therefore, due to its rapidity and precision, detection techniques based on photonics have appeared as a viable alternative to traditional methods or immunoassay-based methods for rapidly diagnosing viruses and epidemic diseases. Thus, photonics researchers and companies have made significant contributions to diagnostics and personal protection equipment through integrating advanced systems and creating revolutionary developments in this area [8][9][10][11].

Coronavirus families are a complex collection of viruses and can cause moderate to severe respiratory infections in humans and animals. Two types of zoonotic-coronaviral high pathogens, such as SARS and MERS viruses, occurred and caused a lethal respiratory disease in humans in 2002 and 2012 and became a new public health issue in the 21st century. In late December 2019, several health facilities in Wuhan, Hubei Province, China, reported clusters of patients with pneumonia of unknown cause [12]. Coronavirus groups are classified into four genera: Alpha-coronavirus, Beta-coronavirus, Gamma-coronavirus, and Delta-coronavirus [13].

Previous studies have reported the detection and classification of specific viruses via quantitative analysis and sorting of viruses and other particles in the micron and nanoparticle size ranges using light scattering and fluorescence measurements. An approach based on surface-enhanced Raman scattering (SERS) was reported in the literature to build optical sensors for influenza virus detection [14]. Research demonstrated the detection of COVID-19 virus in saliva using the Raman spectroscopy analysis tool, with an accuracy of 91.6%, a sensitivity of 92.5%, and a specificity of 88.8% [15]. A study showed that the implementation of virus lasers is similar to an analytical platform for biological diagnosis without investigating immobilization or multiple wash stages [16].

2. COVID-19 Identification via Photonics

Viruses are the smallest molecules of pathogens known. However, most of them cause significant deterioration of human health. This section discusses the essential parameters that contribute to improved COVID-19 diagnosis by photonics on surfaces such as a laser spectrum with molecules and identifies parameters of a laser device to enhance detection of viruses.

However, they cannot understand the biological structures because the light is often insensitive/blind to the distribution pattern of the constituent molecules due to a mismatch in wavelength scales between the virus size and wavelength of the laser. Interactions between light and matter make a significant contribution in many scientific areas, creating critical spectroscopy applications, sensing, quantum information extraction, and lasers. Several studies have explored the effects of combining novel laser beam techniques with molecules and have provided a wealth of new knowledge on the structure of atoms and molecules [17][18][16][19]. When reacting with materials, it can cause ionization effects, according to the ascending order of wavelengths such as gamma rays, X-rays, ultraviolet rays, visible light, infrared rays, and microwaves.

The electron atom lifts it to the upper energy level by consuming the energy of the photon, creating up- and down-transitions between energy levels that are called spontaneous emission. The emitted photons contain energies peculiar to that substance, as each material has a particular collection of energy levels. The frequency (v) and wavelength (λ) of the light are related to these photon energies by The effectiveness of the laser application tool in the COVID-19 battle has many applications such as remote monitoring, tele-screening/telehealth, intelligent networks and big data, improving environmental quality, and improving the quality of foods.

As a result, the lasers are classified as solid-state, liquid, or gas lasers. Among the essential medical lasers are CO2(carbon dioxide), excimer (e.g., XeF), and Ar (argon) lasers. Liquid lasers include dye lasers, while solid-state lasers include ruby or Nd:YAG lasers. The three types are UV lasers, visible lasers, and infrared lasers.

According to the above equation,cis the concentration,dis the particle diameter,θis the measurement angle,λis the wavelength of light, andnis the refractive index of the particles compared to the surrounding medium scattering theory. Light scattering variables include wavelength, particle size, refractive index, incident angle, and concentration [20], as shown in **Table 1**.

Table 1. Keys of light scattering to enhance diagnosis of viruses.

Parameters of Laser Device	Description
Wavelength (λ)	The intensity of the scattered light reduces as the wavelength increases (inversely proportional). This outcome depends on the particle size, and for small particles, it is more pronounced.
Particle size (d)	Scattered light strength is highly dependent on the size of the particles.
Refractive index (n)	The scattering intensity is directly proportional to the difference in the particle’s refractive index and the medium. The smaller the difference, the lower the scattering intensity.
Scattering angle (θ)	The scattering intensity depends on the light angle of the incident.
Concentration (c)	The intensity of the scattered light is proportional to the size of the concentration.

3. Detection of COVID-19 Using Light Technologies

Our study focused on reliable sources in the literature review and examined and summarized 12 empirical studies of COVID-19 detection using laser techniques. This category includes research on photonics-based methods and applications for COVID-19 identification. the collected sample methods from patients, sample preparation, sample storage, and extraction RNA before use of laser techniques such as fluorescence methods, surface-enhanced Raman scattering spectra, surface plasmon resonance (SPR), and Raman scattering with SPR integrated. More importantly, we highlight the detection of COVID-19 based on photonics methods and the practical techniques suitable for reducing the spread of the epidemic.

This method employs fluorescence techniques to determine the presence of COVID-19 RNA. Detection of the SARS coronavirus protein in human serum samples was achieved using a fiber-optic biosensor based on localized surface plasmon coupled fluorescence (LSPCF) at the limit of detection 1 pg/mL The method uses a laser multiwavelength excitation and receiving system which collects the imitated signals such as scattered light and fluorescence from the laser-interrogated target [21]. While the cycle threshold (CT) is established by the number of PCR cycles needed to report quantifiable fluorescence, fluorescence is greater than the threshold of the fluorescence signal.

It has a number of advantages, including high selectivity due to the possibility of a special fingerprint signature, no signal interference from the analyte medium, single molecule detection, the ability to conduct multiplex sensing with a single laser beam, a high throughput, and applicability using commercially available portable Raman detectors [22]. A diagnostic of COVID-19 was developed based on surface-enhanced Raman scattering (SERS) combined with microfluidic systems that involve connected microchannels conjugated with Au/Ag-coated carbon nanotubes. The tool is used to detect viruses from various biological fluids, such as saliva, nasopharyngeal secretions, and tears [23]. Moreover, there are the problems of a weak signal and low sensitivity with a low protein concentration.

The resonance state necessary to accomplish SPR is as shown in Equation (3):(3)εpsinθres=εm εdεm+εd whereεp,εm, andεddenote the dielectric constants of the substrate (prism, optical fiber backbone, etc.), a plasmonic material (metals), and a dielectric layer (analyte medium), respectively, andθresdenotes the incident resonance angle. According to published studies, optical biosensors such as SPR and LSPR have been extensively used in lab conditions to identify virus strains, such as those associated with SARS and MERS, and have been established commercially since the early 1990s [24]. In terms of plasmonic sensors, there are a few reports of COVID-19 detection using a variety of methods, for example, LSPR–sidelong flow [25], the LSPR–DNA selection approach [26], and the LSPR–PCR model. The biosensor artificially created DNA receptor sequences complementing the RNA genome parts of COVID-19 based on nanoparticle gold constructs on a glass substratum.

E. Kim and colleagues introduced a new optical method, called multiplex SERS detection, based on fluorophore separation from the post-PCR requirements without modifying the primer and probe sequences and plasmonic sheet for detection capability for COVID-19. It uses silver nanodots on a plasmonic sheet to enhance the sensitiveness of the biosensor based on LSPR [27]. 85]. **Table 2** shows an outcome analysis of studies on the diagnosis of coronaviruses based on laser techniques. **Figure 1** the following details: part (A) shows plasmonic surface resonance structures such as traditional plasmonic based on a coupled prism, plasmonic based on the grating (long/short) period, and plasmonic based on a waveguide; part (B)

Table 2. Analysis of studies in the literature on the detection of coronavirus disease (COVID-19) based on laser techniques.

Photonics Technique	Target of Virus	Material Coating	Limit of Detection	Wavelength	Diagnosis of COVID-19		Time Duration	Ref.
					In Clinical	On Surfaces		
LSPCF	SARS/nucleocapsid protein	Graphene sheet	0.1 pg/mL	658 nm	✓	×	10 min	[60]
Fluorescence	COVID-19 RNA	Gold	1000 TU mL^{-1}	NA	✓	×	2–3 h	[59]
LIF-LiDAR	COVID-19, Zika, Ebola	NA	9.59×10^4 PFU/cm^2	266–550 nm	✓	×	NA	[61]
SERS microfluid	COVID-19	Au/Ag	NA	NA	✓	×	~few min	[66]
SERS	COVID-19	Gold nanoparticles	17.7 pM	785 nm	✓	×	5 min	[67]
SPR	SARS/ N-protein	Quantum dots	0.1 pg mL^{-1}	345 nm	✓	×	1 h	[75]
SPR	Coronavirus/ N-protein	NA	2.17 nM	214 nm	✓	×	20 min	[76]
LSPR	COVID-19/ spike protein	AuNIs	0.22 ± 0.08 pM	532 nm	✓	×	800 s	[80]
P-FAB	COVID-19/ antibody IgM and IgG	AuNP	106 particles/mL	520–545 nm	✓	×	15 min	[81]
EWA-LSPR	COVID-19/ antibody IgM and IgG	Gold nanoparticle	37 pM	LED	✓	×	1 h	[82]
SERS-LSPR	MERS	Silver nanodot	1–106 nM	500 to 800 nm	✓	×	NA	[83]
SERS-LSPR	COVID-19	Silver nanodot	153.53, 230.37 pM	526 nm 558 nm	✓	×	More 2 h	[84]

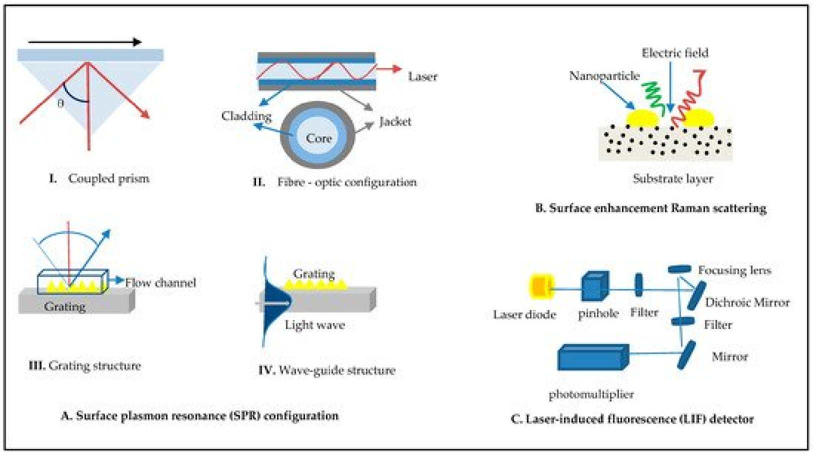

Figure 1. Illustration of light technologies' structures: (A) surface plasmon resonance (SPR) configuration, (B) surface enhancement Raman scattering, and (C) laser-induced fluorescence (LIF) detector.

4. Opportunities and Limitations

Several detection techniques for diagnosing viral infections have been established depending on the type of virus and its properties and the sample obtained from infected patients. False negative outcomes from actual COVID-19 patients may have negative consequences, including delayed treatment for critically ill patients and a high chance of asymptomatic transmission. The World Health Organization has listed many distinct explanations for false negative findings [8]. confuse specimen selection, resulting in false negative findings [28][29].

As a result, we need more effective methods to identify COVID-19 rapidly. This study has evaluated our modern knowledge of the various optical biosensor techniques used to identify viruses and the potential rapid diagnosis of more people to contain the spread of this virus. **Figure 2** shows an overview of sample collection, preparation, storage, and extraction steps before diagnosis and challenges of laser techniques. The issues are provided in**Table 3**, and the challenges of laser diagnosis techniques of COVID-19 are explained.

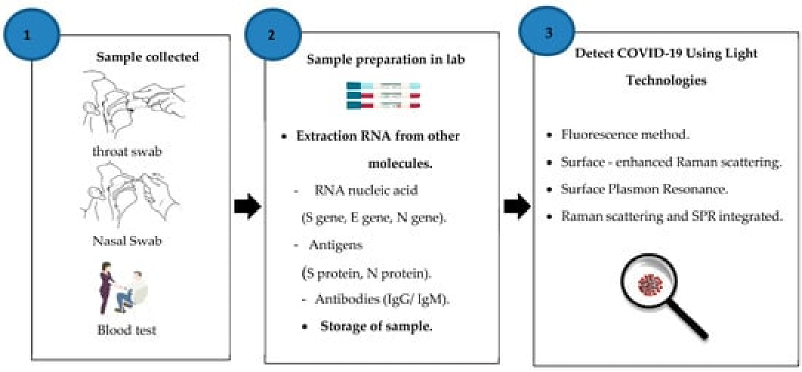

Figure 2. Steps to detect COVID-19 using light methods.

Table 3. The challenges of laser diagnosis techniques of COVID-19.

Laser Diagnosis Techniques	Limitations
Fluorescence method	• Collection of sample consumes time. • Low sample size. • Fluorophore has a short lifetime. • Interference is possible.

Laser Diagnosis Techniques	Limitations
Surface-enhanced Raman scattering	• Weak signal relative to background. • Low sensitivity with low protein concentration. • Laser wavelength is unstable. • Consumes time to collect sample. • Noise signal interference.
Surface plasmon resonance	• Low selectivity. • A small perception depth. • Mass transport challenge. • Heterogeneity of surface. • Misinterpretation of data. • Collection of sample is time-consuming.
Raman scattering with SPR integrated	• Collection of sample consumes time. • Weak signal. • At high analyte concentrations, there is failure to identify to virus, and identification is nonlinear. • Nonuniform absorption of the molecules onto the nanoparticle surface leads to a decrease in signal intensity.

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