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Brain sensor and communication model using plasmonic microring antenna network

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Abstract

In this paper, the feasibility of using multi-plasmonic sensing probes embedded nanoring resonators within a microring resonator system for brain signal probing and the investigation proposed. The plasmonic sensor probes made of gold grating placed within the center nanorings, from which the sensor network of the coupling light from the multi-plasmonic probes to the main ring established. The coupling between light (photon) power and nanogold grating generate the plasmonic polariton dipoles and propagate within the system. The whispering gallery mode generates at the center rings, which will couple into the sensor probes and the induced change in optical signals that can detect via the system ports. The coupling between the generated polaritons and external stimuli from the sub-brain cells will change the optical output signals, where the electro-optic signal conversion can be applied. In manipulation, the changes in the grating periods of the sensing probes will affect the changes in the output signals, which can distinguish by the sensing probe signal Bragg wavelengths. The optical filter applied at each of the device port to attenuate the output signal that can be applied for brain investigation. The simulation results have shown that the low output power can detect for sub-level investigation.

Keywords Brain cells communication · Brain sensor network · Brain investigation · Cells communication

1 Introduction

The human brain consists of cells that can communicate in general via wireless and cable links, where the transmission can form by the plasmonic antenna and liquid core waveguide, respectively (Poznanski et al. 2017; Yousif and Samra 2013). Therefore, the deep-level behaviors among cells can accommodate by quantum physics (Poznanski et al. 2019), which requires the tiny (probes) tools for realistic investigation. Currently, the equipment for brain cells investigation based-on the electrical signals, which cannot probe the sub-level information known as quantum sub-consciousness, where

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investigation of the sub-level brain cells communication is rare. Here, the related works in both communications and sensors found in the references (MacKay 1968; Trehub 1971; Miyazaki et al. 2016; Amiri et al. 2017; Pei et al. 2012), where we have learned that the use of particle aspect of wave-particle duality has the challenge, where the photon applied for the electron excitation within the system. By using the material surface wave, the Drude model can accommodate this phenomenon (Tunsiri et al. 2019), where the key concept is the plasmon waves formed by the coupling between electron and photon on the metal surface, where the wave-particle aspect known as a polariton generated and oscillated within the metal. The advantage of it is the small size antenna, which is useful for the small scale system application. Cell behaviors can affect to the polariton dipole and couple to the system, moreover, the small scale system such as an atom, molecule, and cells can form the nano-communication aspect (Youplao et al. 2018). Some developed metamaterial structures proposed for THz frequency biosensing applications, such as the unit cell composed of a substance with a semiconductor material film to detect the Basal Cell Carcinoma of skin cancer (Keshavarz and Vafapour 2019), to identify the Avian Influenza Viruses (Keshavarz and Vafapour 2019), and the combination of cut wires and split-ring resonator to evaluate the concentration of lung cancer cell (Yang et al. 2019). These plasmonic nanostructures have also shown the potential advantage for biomedical sensors, human health, and food industry (Vafapour 2017, 2019; Shukla et al. 2019; Vafapour and Ghahraloud 2018; Habib et al. 2018, 2019). The nano-antenna embedded with the system, in which the whispering gallery mode and gold grating introduces the dipole oscillation, where the fraction of light power coupled into the system. The technique to have the WGM output from the similar system found in various references (Ali et al. 2018), from which the WGM can control by the coupling constants of those nonlinear rings. The electro-optic (WGM) probe can penetrate to brain and cells with the THz frequency, where the coupling effect between electron and brain cells can be probed and reflected the system (Pornsuwancharoen et al. 2018). The use of suitable THz frequency and light power and tissue depth of few hundred micrometers confirmed (Tserevelakis et al. 2017).

In this work, we propose the use of the plasmonic microring antenna network for sub-level probing and interpretation. By using the Drude model, the plasmonic antenna can form within the microring embedded gold grating. Principally, when light couples into the gold grating, the plasmonic wave generates, and the dipole oscillation form by the plasmonic (plasma) wave collision. The change in oscillation frequency (wavelength) of the sensor network acts by brain cells will probe by the output detection, from which the interpretation can perform. The interaction between plasma waves and brain cells can observe through the sub-level by using the polarization or spin detection scheme at the output port. Brain cell interaction from the applied physical parameters affected the sensor system. It can detect and identify by the system outputs in terms of the Bragg wavelength, time and frequency. In manipulation, the grating period of each antenna probe is placed differently to allocate the transmission location and useful for sensor applications. The WGM beam can also generate at the center of the system, which can use for WiFi (Light Fidelity) link aspect (Ali et al. 2019). The various schemes such as electrical, light and magnetic spin detections can apply at the output ports. The applied external modulation is also variable via the add port. The related theory of the plasmonic sensor is given, and the results are interpreted for brain cells sub-level investigation. By using the practical size silicon microring resonator and gold grating, the proposed system has the potential for quantum level sensors, especially, for the quantum sub-consciousness probing and investigation. The numerical programs used a graphical approach called the Optiwave and the MATLAB program. For simplicity, the suitable parameters obtained by the graphical program, the selected parameters applied to the MATLAB program.

2 Background

From Fig. 1, the light probe forms by the plasmonic antenna introduced the coupling effect and coupled the sensor and brain signals. Therefore, the suitable device parameters are required to obtain the whispering gallery mode within the sensing probes and the main ring. The change in the output signals at the nanograting sensor due to the coupling WGM and brain signals will change the detected signals at the output ports. From which the relationship between the manipulated brain and detected signals obtained. The optical field from a monochromatic source formed by $E_z = E_0 e^{-ik_z Z - \omega t}$, where E_0 is the initial electric field amplitude, $k_z = 2\pi/\lambda$ is the wavenumber in the direction of propagation (z-axis) and $\omega = 2\pi\gamma$ is the angular frequency, where γ is the linear frequency. The optical field couples into the system via an input port and circulates within the system. The fraction of optical power controlled by the selected reflector at the output ends, while the optical isolator places at the input end to protect the light source from the system feedback. The fraction of light power coupled into the sensor probes and back to the system. The coupling between light and each nano gold grating within the nanoring sensor induces the plasmonic wave called the plasmonic polariton, which is the electric dipole oscillation on the gold grating surface. By using the Drude model, the dielectric constant is given by:

$$\varepsilon = \frac{D}{\varepsilon_0 E} = 1 + \frac{P}{\varepsilon_0 E} \tag{1}$$

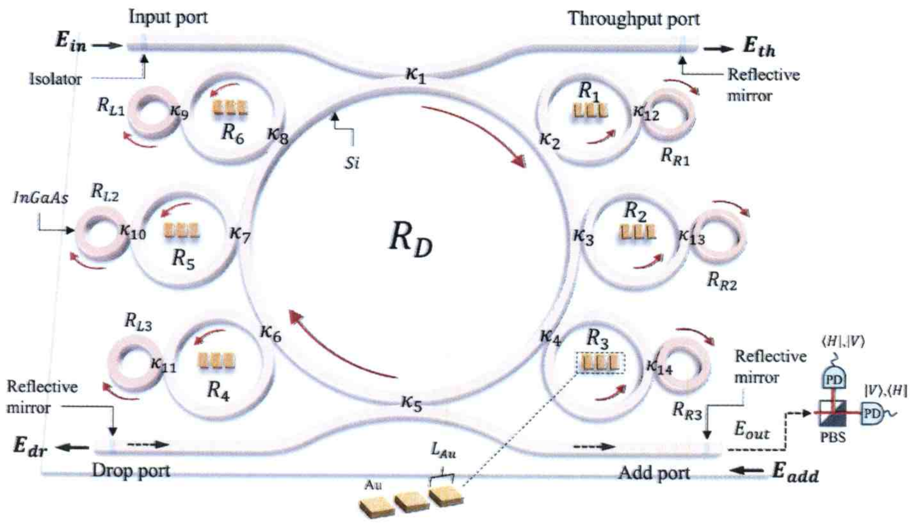

Fig. 1 Schematics of the multi-plasmonic sensor probe system, where E_{in}, E_{th}, E_{dr} and E_{add} are the input, throughput, drop and add port optical fields, respectively. R_i and κ_i are the ring radii and coupling constants. The side rings are silicon ring resonators, where the sensor phase modulators are InGaAs materials. The ring radii are 6.0, 2.0 and 1.10 µm for the main and side rings, respectively. PBS is the polarizing beam-splitter, where <H| and |V> are the horizontal and vertical polarization components, respectively

where D is the electric displacement, P is the polarization density given by $P = -nex$, n is the electron density. The relationship between the polarization and electric field is given by:

$$P = -\frac{ne^2}{m\omega^2}E \tag{2}$$

The frequency-dependent dielectric function is given by:

$$\varepsilon(\omega) = 1 - \frac{ne^2}{\varepsilon_0 m\omega^2} \tag{3}$$

The dielectric function changes from negative to positive, when it is at a resonance frequency ω_p (plasma frequency), and the dielectric function's real part drops to zero. The plasma frequency is given by $\omega_p = \left[ne^2/\varepsilon_0 m\right]^{1/2}$, which is the plasma frequency oscillation. The plasma frequency of obtained graphically from the result, the normalized intensities of the system are as shown by the following equations.

$$\frac{I_{th}}{I_{in}} = \left|\frac{E_{th}}{E_{in}}\right|^2 \tag{4}$$

$$\frac{I_{drop}}{I_{in}} = \left|\frac{E_{drop}}{E_{in}}\right|^2 \tag{5}$$

where E_{in} is the input optical field, the change of the coupling power and dipole oscillation frequency within the system depends on the grating dimension, which is related to the Bragg wavelength, given by $\lambda_B = 2n_e\bigwedge$, where n_e is the effective refractive index of the grating in the waveguide (Amiri et al. 2018), and $\bigwedge$ is the grating period. The other effect is the nonlinear Kerr effect, which is given by the relationship as $n = n_0 + n_2 I = n_0 + n_2 P/A_{eff}$ (Ariannejad et al. 2018), where n_0 and n_2 are the linear and nonlinear refractive indices, respectively (Ariannejad et al. 2018; Amiri et al. 2018). I is the optical intensity and P is the optical power, where A_{eff} is the effective mode core area of the device (Amiri et al. 2018a, b). For the microring resonator, the effective mode core areas range from 0.10 to 0.50 µm^2. Currently, Silicon has the potential of fabrication with the ring radius up to 1 µm reported (Prabhu et al. 2010).

3 Simulation results and discussion

Figure 1, the input light source with a wavelength of 1.55 µm fed into the system via the add port. The selected parameters applied, from which the required WGM beams obtained as shown in Fig. 2. The different grating periods of each sensor probe lead the sensor location allocated. The coupling output of the sensor and brain cells reflect the system and detect at the system outputs. An optical isolator placed for optical feedback protection. The metal (gold) filter applied at the add port to allow the required attenuation for the sub-level signal detection. The cable connection can also apply to the throughput and drop ports for long-distance transmission. The network sensors connected by the main ring, which can identify by the output signal. The change induced by

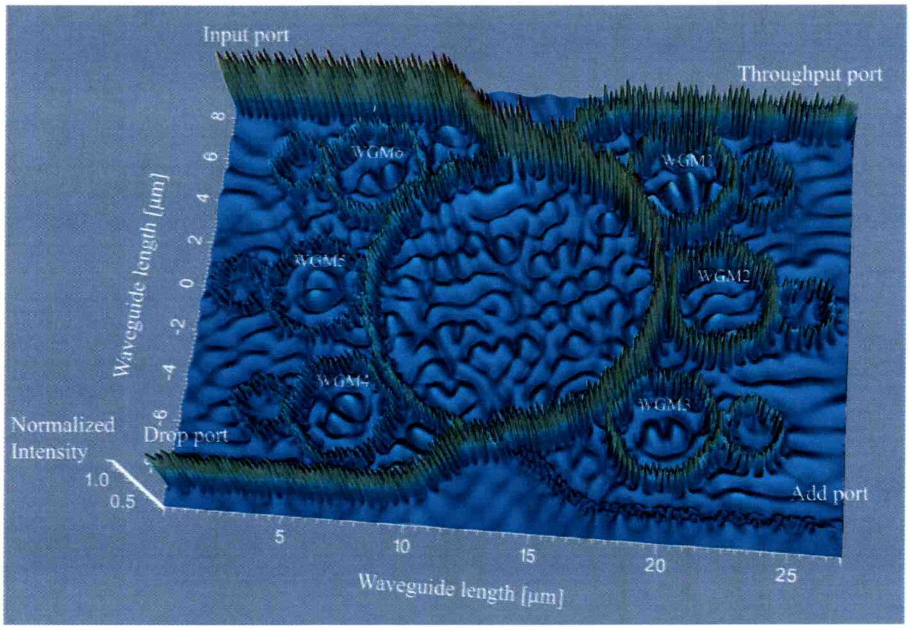

Fig. 2 The selected WGM output using the suitable parameters, where the program is the Optiwave. The input power is 10 mW at the center wavelength of 1.55 μm, the waveguide loss is 0.5 dB mm^{-1}, the core effective area is 0.30 μm^2. The required feedback and transmittance are controlled the gold filter at the ends. The low power output detection can apply at the add port

brain cells network from the reference signals and distinguished, which allow forming the brain cell communication. The network of the sensors can be connected by the main ring, which can be identified at the output detection. The change induces by brain cells will change from the reference signals and distinguish, which allow forming the brain cell communication. The related parameters are given in the figure caption, the results obtained shown in Figs. 2, 3, 4 and 5. The plot of the normalized intensity and (a) wavelength-frequency, and (b) time domains with the same grating dimension and input power are shown in Fig. 3. The plot of the normalized intensity and wavelength-frequency of 6 different grating periods, with the input power of 10 mW is shown in Fig. 4. The plots of the normalized intensity and frequency of the comparison results between the same and different grating periods with the input power of 10 mW are shown in Fig. 5, where (a) throughput port, (b) WGM at the center ring, (c) drop port, and (d) add port. The Bragg wavelength of the output signals clearly confirmed and identified, where the change induces by brain cell information causes the change in Bragg wavelength detected at the output ports.

The identified antenna nodes connected to the sub-level brain cells, where the exchange information between brain cells and electric (polariton) dipoles reflected the system and observed at the add port (Ali et al. 2018). The measurement can be available by light, spin by the polarized output, which can attenuate to the single-photon detection, which can link to the sub-level called quantum consciousness. The network of cells can also investigate by the link between the brain cells and device nodes. The number of probes can also increase for a large volume of investigation. The number of a system

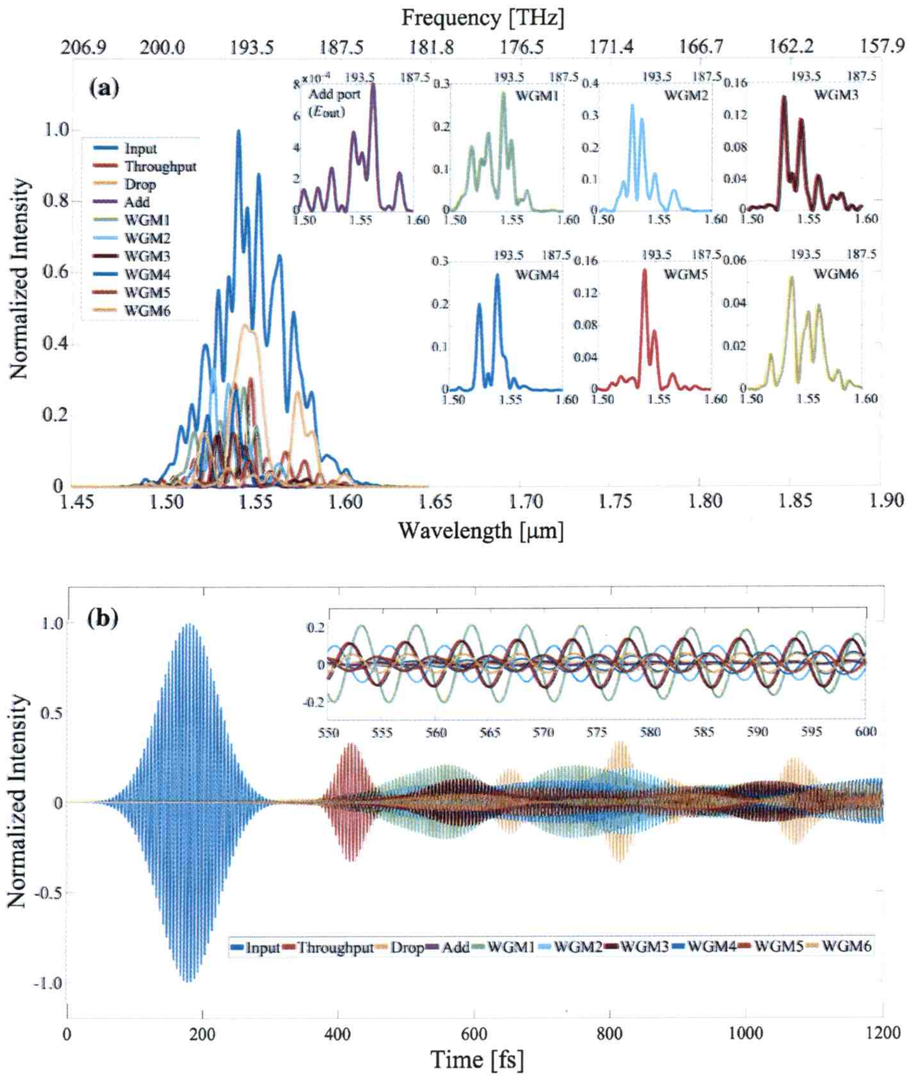

Fig. 3 Plots of the normalized intensity and **a** wavelength, **b** frequency, **c** time domain with the same grating dimension and input power, the gold grating dimension is 0.4 μm×0.4 μm with 0.2 μm thickness, placed at a distance of 0.20 μm of each grating. The refractive index of Si: $n_{Si}=3.47$, *InGaAs*: $n_0=3.14$, $n_2=1.3\times10^{-13}$ $m^2\ W^{-1}$

can also increase for large volume investigation by the same principle. Recently, the various works have reported that communication among cells may successfully accommodate (Poznanski et al. 2017), where the polariton wave propagated in the liquid core waveguide (blood vessel), from which the communication information formed by the electron clouds and cells. Another challenging aspect is the cells communication via the wireless link, where the wave propagation formed by the electron cloud dipoles in the plasmonic layers and oscillation. The report of the plasmonic antenna has also reported

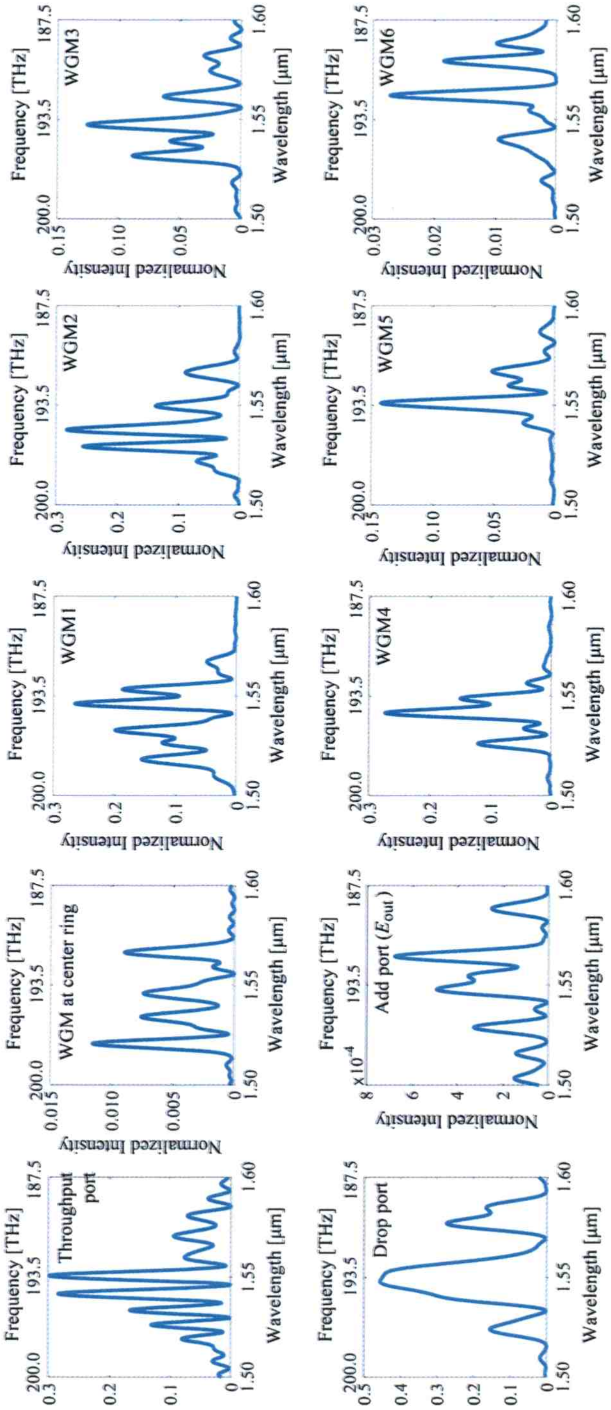

Fig. 4 Plots of the normalized intensity and wavelength-frequency with 6 different grating periods, the gold grating dimension is 0.4 µm × 0.4 µm for WGM1 and increasing in size of 0.05 µm for WGM2 to WGM6, respectively. The input power is fixed to 10 mW

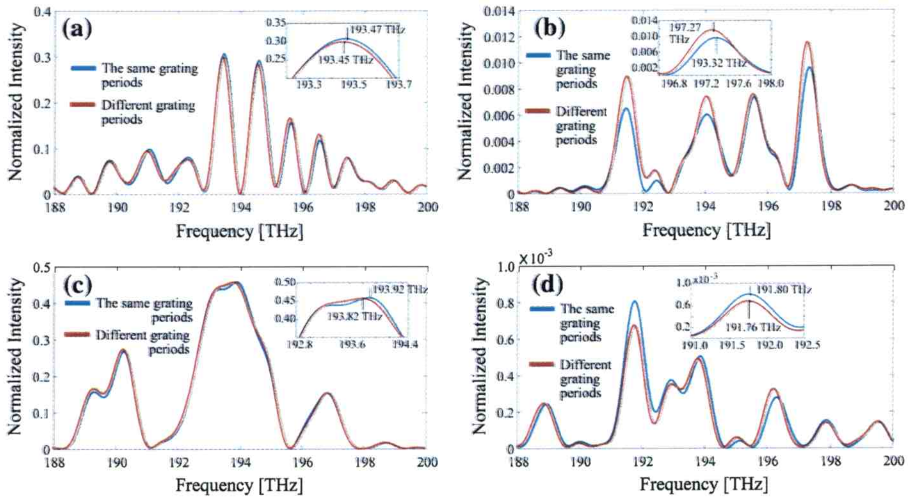

Fig. 5 Plots of the normalized intensity and frequency, where the comparison results between the same and different grating periods with the input power of 10 mW, where **a** throughput port, **b** WGM at the center ring, **c** drop port, and **d** add port. The discrepancies of the Bragg wavelengths of the sensor probes, which can use for brain cell network. The add port signal can attenuate, which allows having low power detection, especially, for quantum sub-consciousness

(Cubukcu et al. 2006). Eventually, the electric dipoles generated by electron cloud in the molecules are available for the information carrier, where the spin encoding can be formed and detected at the output. By the combination of the wireless and cable links, therefore, the sub-level of brain cells communication can observe to the sub-consciousness investigation may be possible.

4 Conclusion

We have proposed the use of the microring network for sub-level brain cell sensors and communication. The sensor network formed by the 6 microring probes connected the main microring resonator. The coupling between electron clouds and polariton dipoles induced the change in the output signals, which introduced the changes in Bragg wavelengths (frequencies) seen at output ports. The different sensor nodes can identify by the different Bragg wavelengths formed by the different grating dimensions, from which the relationship between them can provide the required information, especially, for the sub-level brain signals, where the feasibility for quantum sub-consciousness investigation can be possible. In an application, the sensing signals with the frequency of THz can apply and penetrate to the sub-level brain cells. The interaction between the brain signals and the sensors can detect and characterize. The number of sensor probes can increase for lager coverage volume of investigation.

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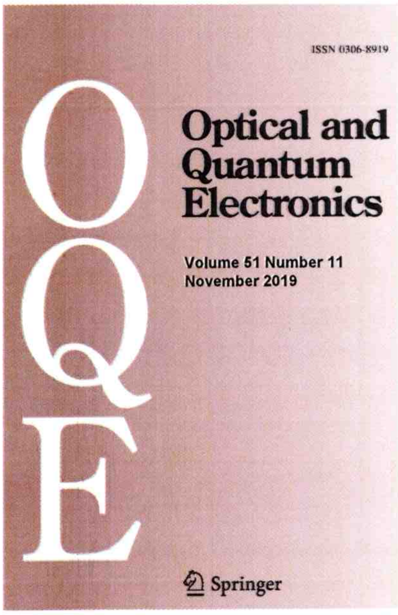

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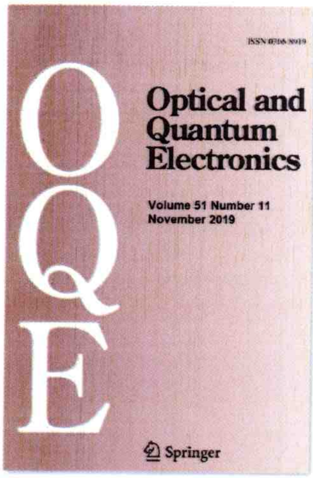
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