A proposal for optomechanical bichromatic wavelength switching for two-color up-conversion application

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Abstract
This study focuses on the Optomechanical bichromatic wavelength switching system as an indirect two-color up-conversion process that relies on optical force and nanorod scattering effects. This system is used to control light coupling between four parallel optical waveguides made of silicon nitride (Si₃N₄) which form two identical parts. The parallel waveguides with 0.5 μm × 0.5 μm cross-section and 220 μm lengths are suspended on a silica (SiO₂) substrate embedded with the array of square silicon (Si) nanorods. By mid-IR plane wave illumination, as control light, with different intensities and different wavelengths on nanorods, scattering would increase and result in an improvement in attractive gradient optical force exerted on waveguides. Via bending waveguides toward each other, caused by optical gradient force, two different visible lights, as probe signals, propagating in the first waveguide of each section would couple to the adjacent waveguide. Simulation results reveal that when the distance between the parallel waveguides in the equilibrium position is 100 nm and the intensity of mid-IR light is 1.28 mW/μm² total coupling would occur in two situations: 1- when the control light is 4.5 μm, the probe light with 713 nm wavelength is transmitted to the output, 2- when the control light is 3 μm, the probe light with 609 nm wavelength is transmitted to the output. In the first case 1.92 pN/μm optical force is needed to bend each waveguide by 9 nm and in the second one, 1.28 pN/μm optical force is needed to bend each waveguide by 6 nm for total coupling. The efficiency of the coupled waveguides system is %88.6 for 609 nm probe light injection and %96.5 for 713 nm probe light injection.

Keywords Optomechanics · Optical force · Optical switching · Upconversion · Scattering · QDs

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1 Introduction

Radiation pressure and gradient force are generally acknowledged to be influential upon the movement of micro and nanoparticles. This impression is the result of light’s momentum nature and its competence for transmitting the energy to matter which results in movement through interaction. Radiation pressure and gradient force as the major classification of optical force are crucial in this interaction which is closely related to the momentum conservation of light (Li et al. 2008; Roels et al. 2009; Xin et al. 2020). The radiation pressure force, for the direction of its motion, is parallel to light, which in turn, is because of the electromagnetic waves’ bouncing back after hitting the object (Metcalfe 2014; Farman and Bahrampour 2013; Cripe 2020). When light passes through the object, it brings about a gradient force that is perpendicular to the propagation, because of refraction. The non-uniform electromagnetic field, moreover, is another reason for the origination of gradient force (Xin et al. 2020; Wang and Ding 2019; Zhao et al. 2020).

In the 2nd half of the twentieth century, the optical force effect on the dielectric microsphere was first observed by Arthur Ashkin in his experiments. This mechanism was continued by constructing an optical tweezer which was a method for trapping and controlling nano and microscale particles (Ashkin et al. 1986). Physical, biological, and material sciences from then on used optical force effect. These fields utilized different types of optical tweezers for trapping and manipulating dielectric particles (Liu and Zhao 2014), metallic particles (Hajizadeh and Reihani 2010), biological objects such as cells, bacteria, viruses (Ashkin and Dziedzic 1989; Komoto et al. 2020), and nanometer precision sorting of nanoparticles (Shi et al. 2018; Nan and Yan 2018). Plasmonic constructions have been advanced to reduce the diffraction limit of standard optical tweezers and increase gradient force in near field operations (Grigorenko et al. 2008; Juan et al. 2011; Aghadjani et al. 2018) and opto-microfluidic makeup proved to be useful for manipulating, separating, and imaging entities suspended in fluids (Xu et al. 2018; Chen et al. 2019; Paiè et al. 2018; Yao et al. 2020; Wang et al. 2005).

Light propagation through the waveguide creates an evanescent field that may be applied in various applications. For instance, this force may be functional in trapping and manipulating biological targets by the use of nano-fibers (Xin et al. 2013) and driving nanomechanical resonators embedded in integrated silicon photonic circuits (Li et al. 2008). In the same vein, optical tunable micro-photonic devices employ attractive and repulsive forces arising from overlapping waves that are guided through parallel waveguides (Roels et al. 2009; Povinelli et al. 2005). Also, tuning the sign of the optical force from attractive to repulsive can be done by injecting lightwaves of different phases to coupled waveguides (Pernice et al. 2009). Using light control with light mechanisms in nano-optomechanical systems is an alternative for all-optical signal processing (Zhang et al. 2020; Shalin et al. 2014). Still more, optical switches are further instances of light control mechanisms in which light is fundamental. All-optical fiber-chip-fiber switch operating via radiant thermal power is a case in point (Liu et al. 2017). Optical gradient force enlarges by stirring up surface plasmon modes between graphene sheets (Zhang et al. 2017) or suspended graphene over semiconductor/dielectric waveguide for sensing applications (Dash et al. 2020, 2019). Optical gradient force, in addition, is used to drive a two-state memory structure in a combination of a ring and a waveguide which can be used in all-optical computing (Dong et al. 2015). The hybrid plasmonic waveguides including a combination between surface plasmon modes and waveguide modes are a similar construction. This construct is competent to enable effective optically trapping of nanometer dielectric particles (Yang et al. 2011; Li
et al. 2013). Another instance of gradient force among waveguides is the mid-IR to visible switching system which can be used for the indirect up-conversion process which consists of parallel waveguides suspending over a substrate and embedded with metal-dielectric nanoparticles (Fanid and Rostami 2021). Wavelength up-conversion is typically a nonlinear optical event in which energy transfer happens. Such an enhancement in wavelength is done by irradiating low energy waves to nonlinear materials and by emitting higher energy waves (Liu et al. 2015; Haase and Schäfer 2011).

The exact measurement of movement on a nanometer scale needs big scrutiny. An instance of this is mechanical motion in the fiber-taper NOM system which causes the Femto-newton sensing of the optical force on nanofiber (Yu et al. 2018; Zheng et al. 2019).

Different scattering behaviors are seen in the interaction of electromagnetic waves with nano-objects at wavelength ranges from visible to infrared such as the scattering profiles of a silicon nanosphere with a radius of 75 nm changing with light illumination in the visible spectral range (Fu et al. 2013). Also, exciting single core–shell nanoparticles with various sizes cause interference between different orders of the electric and magnetic moment. This interaction takes place in specified circumstances i.e. \( a_n = b_n \) (Mie scattering coefficients) and could lead to elimination scattering in the backward direction and improving scattering in the forward orientation. In addition, more advancement appears in forward direction by higher-order interferences of magnetic and electric modes (Liu et al. 2014). Further, for the amount of scattering in the forward direction to reach zero, we may use gain-assisted dielectric shell-coated metallic core spherical particles (Shen et al. 2017).

This paper aims to design and simulate a bichromatic optomechanical system to convert two mid-IR wavelengths to two short wavelengths in the visible range. This system is used to control light coupling between four parallel optical waveguides which form two identical parts. The conversion operation is done by switching method and there is no energy transfer between the mid-IR input wavelengths and the visible lights propagating through the waveguides, unlike the usual frequency up-converters in which the energy transfer takes place. In this optomechanical system, nanorods have been used to increase the optical force exerted on coupled waveguides. Mid-IR illumination over nanoparticles and the contribution of the scattering effect would increase the optical force applied to the waveguides.

2 Structure

Figure 1 schematically illustrates the basic structure of the nano optomechanical bichromatic up-conversion system. This structure consists of two identical parts which are used to control light coupling between four parallel optical waveguides. In each section two doubly clamped parallel waveguides made of Si\textsubscript{3}N\textsubscript{4} with \( L = 220 \) µm length and 0.5 µm×0.5 µm cross-section are suspended \( h = 1025 \) nm above the nanorods. The gap between the parallel waveguides in the equilibrium position is 100 nm. The Si square nanorods with the size of \( s = 1050 \) nm and the triplet arraying method are placed on a glass substrate as a transparent plate to a high-power mid-IR light pump. They are arranged at a certain distance from each other i.e. \( a = 0.5 \times s = 525 \) nm in the order of the size of nanorods. The intensity of the mid-IR pump as control light is about 1.28 mW/µm\textsuperscript{2} and its wavelengths are 4.5 µm and 3 µm. Visible lights with 713 nm and 609 wavelengths as probe signals with arbitrary power are injected into the entrance of parallel waveguides in two sections. The distance between the two sections (\( p = 15 \) µm) is chosen so that the scattering caused by the nanorods does not affect the waveguides of the other section.
The emission of intermediate infrared light waves with wavelengths of 3 μm and 4.5 μm, creates different attractive forces between the paired waveguide and the electric field magnitude between them would increase, considering the backward scattering from the nanorods. As a result, raising the applied optical force would cause the waveguides to deviate. With bending both adjacent waveguides towards each other about 9 nm, visible light with 713 (red) nm and 609 (orange) wavelengths as probe signals are injected into the entrance of parallel waveguides in two sections. The distance between parallel-coupled waveguides, d is the distance between parallel-coupled waveguides, h is waveguides’ height from the top of the nanorods, a is the distance between nanorods, p is the distance between two sections of the structure. c) z-y view of the structure, L is the length of suspended waveguides.

The emission of intermediate infrared light waves with wavelengths of 3 μm and 4.5 μm, creates different attractive forces between the paired waveguide and the electric field magnitude between them would increase, considering the backward scattering from the nanorods. As a result, raising the applied optical force would cause the waveguides to deviate. With bending both adjacent waveguides towards each other about 9 nm, visible light with 713 nm wavelength that is passing through the first waveguide would couple to another and may be observed in the output of the neighboring waveguide. Besides, if the deflection is 6 nm, the other probe signal with a 609 nm wavelength can be transmitted to the output.

For using scattering nanorods in certain mid-IR wavelengths, i.e. 3 μm and 4.5 μm, various square rods were simulated; these are the wavelength regions that can react with the tissues of the human body (Junaid et al. 2019). In the process of this simulation, changing the side size of the square silicon rod indicated that when the size is 1050 nm, scattering in the mid-IR range raises. Other parameters such as the gap between waveguides (d), and the height of the waveguides above the surface of the Si nanorod array (h), are modified through several simulations. It needs to mention that the distance between the nanorods (a) is approximately the same as the side size of the nanorods.
3 Methodology

For the investigation of the optomechanical two-color up-conversion mechanism, we studied two physical theories i.e. optical force and scattering by nanorods.

3.1 Optical force

In this research, the optical force exerted on the coupled waveguides has been used as a driver for deflecting waveguides, therefore, it should be calculated on the desired volume. Here, the optical force is calculated by FDTD (finite difference time domain) numerical solution method by the time average of integrating the Maxwell stress tensor over the cross-section of each waveguide separately in the $x$–$y$ plane. Maxwell’s stress tensor is described as follows (Dash et al. 2019):

$$
\psi_{ij} = \varepsilon_0 \left( E_i E_j - \frac{1}{2} \delta_{ij} E^2 \right) + \frac{1}{\mu_0} \left( B_i B_j - \frac{1}{2} \delta_{ij} B^2 \right)
$$

(1)

In Eq. (1), $i, j \in x, y, z$, $E_i$ and $B_i$ are the amplitude of electric field intensity and magnetic flux density, $\delta_{ij}$ is Kronecker delta function, and $\psi_{i,j}$ is MST element at a single point.

3.2 Scattering of nanorods

Irradiated light waves interact with the nanorods placed on the SiO$_2$ substrate and scatter the light in the backward and forward directions which increases the strength of the electric field between the coupled waveguides. As the micro and nanoscale particles move towards a stronger field intensity (Grigorenko et al. 2008), the attractive force due to the scattering of nanorods will appear as well. Theoretically, Mie’s theory is used to analyze the scattering of spherical particles which have been influenced by electromagnetic waves. Scattering efficiency (scattering cross-section divided by the cross-section of the particle) for spherical and core–shell objects is (Liu et al. 2014; Shen et al. 2017; Bohren and Huffman 2008):

$$
Q_{sca} = \frac{2}{k^2 R^2} \sum_{n=1}^{\infty} (2n + 1) \left( |a_n|^2 + |b_n|^2 \right)
$$

(2)

In Eq. (2), $k$ is the wavenumber, $R$ is the radii of the most ou layer of the core–shell object, $a_n$, and $b_n$ are the Mie scattering coefficients which refer to $n$th electric and magnetic moments respectively. Also, scattering intensity (SI) in the far-field region is as follows (Liu et al. 2014; Shen et al. 2017; Bohren and Huffman 2008):

$$
SI(\theta, \varphi) = \frac{\lambda^2}{4\pi^2 d^2} \left[ |T_1(\cos \theta)|^2 \sin^2 \varphi + |T_2(\cos \theta)|^2 \cos^2 \varphi \right]
$$

(3)

In Eq. (3), $\lambda$ is the incident wavelength, $d$ is the distance from to the position where the intensity of scattering is measured to the center of the spherical particle, $\theta$ is polar angel and $\varphi$ is the azimuthal angle. $T_{1,2}(\cos \theta)$ are detailed to:

$$
T_1(\cos \theta) = \sum_{n=1}^{\infty} \frac{2n + 1}{n(n + 1)} \left[ a_n \pi_n(\cos \theta) + b_n \tau_n(\cos \theta) \right]
$$

(4)
\[ T_2(\cos \theta) = \sum_{n=1}^{\infty} \frac{2n+1}{n(n+1)} \left[a_n \pi_n(\cos \theta) + b_n \pi_n(\cos \theta)\right] \]

which \( \pi_n(\cos \theta) = P_n^1(\cos \theta)/\sin \theta \), \( \pi_n(\cos \theta) = dP_n^1(\cos \theta)/d\theta \) and \( P_n^1(\cos \theta) \) is the first order of Legendre function.

In this work, nanorods with a square cross-section are used for the convenience of the manufacturing process (Tsuchizawa et al. 2008; Chandran et al. 2017) and the scattering efficiency of nanorods is calculated with the numerical FDTD solution method in the cross-section of nanorods in the \( x-y \) plane.

4 Results and discussion

To investigate and simulate the structure which is used in the article, several procedures have been employed. The optical force over coupled waveguides and the scattering efficiency of a group of Si nanorods are calculated by the numerical FDTD solution process. The modal analysis and coupling between adjacent waveguides are computed through the FDE (finite difference Eigenmode) method and coupled-mode theory of synchronous coupling (Hunsperger 1995). Additionally, the finite element method (FEM) is utilized to specify the mechanical properties of \( \text{Si}_3\text{N}_4 \) nanowire and the temperature response of the optomechanical system.

4.1 Scattering of nanorods

FDTD simulation results are obtained for the array of Si nanorods that are lying upon the silica substrate in Fig. 2. By mid-IR frequency range illumination of the nanorods, as Fig. 2a indicates, the amount of scattering in the forward and backward directions varies concerning the different input wavelengths. In some wavelengths, i.e. 3 \( \mu \)m and 4.5 \( \mu \)m, the scattering rate is increased in the backward direction which can be used in the structure of Fig. 1 to increase the electric field strength between coupled waveguides (Fig. 2b). Arranging the nanorods causes the field to be more oriented in the forward or backward directions. For example, Fig. 2d and e show the distribution of the total electric field magnitude (V/m) (including the input field and the scattered field) for a single nanorod and a triple array of nanorods, respectively. In the nanowire array mode, the field amplitude above the nanorods is increased compared to the single-mode. The data of the material properties are set according to reference (Palik 1998) for Si and \( \text{SiO}_2 \) and reference (Luke et al. 2015) for \( \text{Si}_3\text{N}_4 \). The minimum size of the mesh is set to 10 nm and all of the boundary conditions are set as PML (perfect matched layer).

4.2 Optical force

In the proposed bichromatic optomechanical system, when the mid-IR plane wave is illuminated from the top of the structure on the nanorods (Fig. 1a) and light interacts with them, it causes the nanorods to scatter and increase the attractive optical force among the suspended coupled waveguides. Surveying the simulation results shows that the force exerted on the coupled waveguides depends on the input mid-IR wavelength and the vertical distance between waveguides and the top of the nanorods. Indeed, the various gap
The results obtained in Fig. 3 shows that the electromagnetic wave radiation on the structure of Fig. 1 increases the electric field strength between the coupled waveguides. For example, in Fig. 3b, c, and Fig. 3d a comparison is made for the case where the input mid-IR wavelength is 3 µm and 4.5 µm. It is worth mentioning that where the amount of scattering is high, i.e. 4.5 µm, the field intensity is also higher between the coupled waveguides.

Figure 4 explains the simulation outcome dealing with the optical force in the optomechanical up-conversion system as shown in Fig. 1a. The structure is made up of a triplet arrangement of nanorods to cover the whole portion of the paired waveguides. Moreover, the 220 µm span of the square nanorods in the z-direction provides the condition for
applying uniform optical force along the close waveguides. Also, the 3-bits in the x-direction ensure the symmetry of the exerted optical force. The data of the optical properties are determined according to reference (Palik 1998) for Si and SiO2 and reference (Luke et al. 2015) for Si3N4. The minimum dimensions of the mesh unit are 10 nm and entire of the boundary conditions are PML.

Figure 4a shows making changes to the mid-IR input wavelength or the gap between coupled waveguides alters the amount of applied optical force. For example, when the entering pump intensity is $I = 1\text{ mW/µm}^2$, different gaps ranging from $d = 100\text{ nm}$ to $d = 300\text{ nm}$, would cause the waveguides to experience different forces. Indeed by reducing the distance of the adjacent waveguides in some wavelengths, the applied force increases. Since the waveguides’ approach to one another is noteworthy, optical force is computed in the x-direction. Also by the symmetry of the optomechanical-system construction, the optical force applied on the coupled guides is identical in amplitude but reverse in direction.

To probe the action of the scattering effect on the exerted optical force, the structure (Fig. 1a) is emitted with mid-IR wavelengths by eliminating the nanorods. A comparison between the issues, Fig. 4a and b, shows that the force will be multiplied in several frequencies.

Changing the dimension of Si$_3$N$_4$ nanofibers affects the force applied to the coupled waveguides. Figure 4c shows that increasing the size of nanofibers causes the wavelength at which the input force is maximum to shift slightly toward larger wavelengths. Also changing the distance of the coupled waveguides from the top surface of the nanorods

![Fig. 3](image.png) Calculating the electric field magnitude on the surface of the cross-section of the structure (shown in Fig. 1a). a) Schematic of an incident plane wave on an array of Si rods in which electric field polarized in the x-direction and propagate in the y-direction (the amplitude of electric field is 1 V/m). b) Here nanorods are removed and the input mid-IR wavelength is $\lambda = 4.5 \text{ µm}$. c) The input mid-IR wavelength is $\lambda = 3 \text{ µm}$ and d) the input mid-IR wavelength is $\lambda = 4.5 \text{ µm}$
results in changing the applied optical force, which is because of the type of electric field distribution above the nanorods (Fig. 4d). By examining the results obtained in Fig. 4, the values of parameters are determined; \(d = 100\) nm, \(s = 1050\) nm, \(h = 1025\) nm. The value of parameter 'd' is considered to be 100 nm for applying the maximum amount of optical force. The value of parameter 's' is set to 1050 nm so that the force applied at the wavelength of 4.5 \(\mu\)m has its maximum value. We also change the height to reach the desired amount of force more precisely. Figure 5, also, shows the results by considering the parameters as determined values.

4.3 Mechanical properties of the waveguides

This section investigates the simulation results of mechanical behavior of single Si\(_3\)N\(_4\) with dimensions of 220 \(\mu\)m \(\times\) 0.5 \(\mu\)m \(\times\) 0.5 \(\mu\)m, using the FEM solution method. Poisson's ratio is 0.23 for Si\(_3\)N\(_4\), Young's module is 250 GPa, and density is 3100 kg/m\(^3\) (Shackelford and Alexander 2000). As the waveguide is exerted with different forces, the stationary response of the amount of deflection on the line crossing the middle of
the waveguide and at its center can be calculated. Because of the small deformation of the waveguide compared to its dimensions, displacement may be assumed linear (Fig. 6b and Fig. 6c). Besides Fig. 6b provides the optical force that is required for the displacement desired.

### 4.4 Coupling between waveguides

To investigate how light is coupled between suspended waveguides, light with two different wavelengths in the visible range is injected into the first waveguide of each section (Fig. 7a). By changing the gap between the coupled waveguides, the amount of light power propagating and coupling will change from the first waveguide to the second one (Fig. 7b–g). In Fig. 7, either of the right and left columns belongs to a section of the structure. In Fig. 7b, d, and f, the visible light with 713 nm wavelength is injected into the first (upper) waveguide; results reveal that in case the distance of the waveguides is equal to 82 nm, the coupling occurs and the signal is transmitted to the end of the second waveguide, which is considered as the output of Sect. 1. But in the other two cases, i.e. \( d = 100 \) nm and \( d = 88 \) nm, the optical power is not transmitted to the output. Meanwhile,
in Fig. 7c, e, and g, the visible light with 713 nm wavelength is injected into the first waveguide. In this case, the power of light is transmitted to the output just when the distance is $d=88$ nm and in the other two situations, the output is low.

It is worth mentioning that to obtain the two visible wavelengths $\lambda=713$ nm and $\lambda=609$ nm, as well as the locations, $d=82$ nm, $d=88$ nm, and $d=100$ nm, where the waveguides will reach equilibrium after applying force, the FDE solution method and
coupled-mode theory, are functional. Through these simulations, the transmittance vs. wavelength and distance is shown in Fig. 8.

Finally, based on the diagrams shown in Figs. 4, 6b, and 7, we conclude that a graph can be derived showing the transmittance of the probe lights compared to the mid-IR light input intensity (Fig. 9). In this way, first, the waveguides for both sections are at the state of equilibrium at a distance of 100 nm from each other and then the mid-IR plane waves would create an optical force, causing coupled waveguides to attract one another. If the mid-IR light intensity is considered to be 1.28 mW/µm², the radiation of two different wavelengths (4.5 µm or 3 µm) will result in the detection of two distinct visible lights (713 nm or 609 nm) in the output. The efficiency of the coupled waveguides system is %88.6 for 609 nm probe light injection and %96.5 for 713 nm. Table 1, also, indicates significant results obtained from the system. The minimum dimension of the mesh unit between the coupled waveguides is set to 1 nm and 5 nm for other regions. The entire boundary conditions are PML.
According to the simulations, the probe light is introduced from the entrance of the excited waveguide. This can be accomplished with gratings Si$_3$N$_4$ upon the SiO$_2$ substrate as grating couplers that are used to couple the probe signal into the waveguide (Hong et al. 2019; Xu et al. 2017). In addition, the layer fabrication process can rely on planner technology, such as lithography and etching (Debnath et al. 2016).

### 4.5 Temperature response

The temperature response of the optomechanical system (shown in Fig. 1) is obtained by electromagnetic wave irradiation with the wavelength of 4.5 μm and the intensity of 1.28 mW/μm$^2$ in Fig. 10. The maximum temperature occurs between Si$_3$N$_4$ waveguides, which reaches 78 °C (Fig. 10a). Figure 10b also shows how the temperature changes vs time, and after about 100 μs the system will reach an equilibrium temperature.

![Fig. 10](image-url)  
**Fig. 10** The temperature response in the one section of the optomechanical system: **a** temperature distribution, **b** temperature in the point between the Si$_3$N$_4$ waveguides. The incoming light intensity is 1 mW/μm$^2$ and 4.5 μm wavelength

| Wavelength | Non | mid-IR = 4.5 μm | mid-IR = 3.5 μm | n: Si$_3$N$_4$ | Loss (dB/cm): Si$_3$N$_4$ |
|------------|-----|----------------|----------------|---------------|---------------------------|
| 713 nm     | Low (%2) | High (%96.5) | Low (%0.1) | 2.0307 | 0.00043 |
| 609 nm     | Low (%6.4) | Low (%0.1) | High (%88.6) | 2.0419 | 0.00065 |

Column 1 lists the wavelengths injected into the waveguides. Columns 2 to 4 show the system outputs for the different wavelengths of the input Mid-IR pump, the intensity is 1.28 mW/μm$^2$. Column 5 is the refractive index of the Si$_3$N$_4$ at two wavelengths on which the simulations are done. Column 6 is the loss of coupling waveguides with $d=100$ nm and a single Si$_3$N$_4$ guide on the substrate.
5 Conclusion

This study surveys the effect of the scattering of electromagnetic fields by the array of square nanorods on an optical-force-based optomechanical system. This system can be used for the bichromatic mid-IR to visible up-conversion process. The study uses two different mid-IR wavelengths as control and two distinct visible waves as probe signals as well. Simulation results illustrate that scattering of nanorods would increase the optical force between suspended coupled waveguides for two identical sections of the structure. When the sufficient mid-IR pump light ($I = 12.8 \text{ mW/µm}^2$) is provided, by selecting the wavelengths between 4.5 µm or 3 µm, the detected light in the output would be $\lambda = 713 \text{ nm}$ and nm $\lambda = 609 \text{ nm}$, respectively. According to the findings of this research, the scattering of nanoparticles enhances the applied optical force in the optomechanical system. The proposed system can be used as a two-color up-conversion system at room temperature.

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**Declarations**

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