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Research Article

MnF_2/SiO_2 Transport Properties of Quasiperiodic Photonic Crystals for Potential Catalytic Applications

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Magnetically recyclable materials should be ideal support in photocatalytic system because they permit the photocatalysts to be recovered rapidly and efficiently by applying an external magnetic field such as, MnF_2. In this paper, MnF_2 and SiO_2 layers constitute a one-dimensional quasiperiodic photonic crystal according to Fibonacci. When the electromagnetic wave irradiates obliquely, the transmission peak moves to higher frequency direction with the angle increasing. Both the number of transmission peaks and the transmission peaks of double-forked structure increase with the increase of structural progression. We also found that the polarization of electromagnetic waves has influence on the transmission properties; TM wave transmission peak half wide is significantly greater than TE wave transmission peak half wide. The band gap near antiferromagnetic (AF) resonance frequency becomes narrow as the intensity of the applied static magnetic field increases. The as-prepared photonic crystal has tremendous potential practical use to eliminate organic pollutants from wastewater.

1. Introduction

The magnetic removal of the photocatalysts composited of magnetic materials has been frequently investigated because such a process can be performed with a minimal use of energy and this approach can be employed for the development of an easily reusable and recoverable photocatalyst. MnF_2 is a typical antiferromagnetic (AF) material with the resonance frequency near 0.3 Terahertz (THz). Its optical properties can be described and researched by the magnetic susceptibility. It is worth noting that magnetization compared with the electric polarization intensity has time reversal nonreciprocal, optical rotation and so on. It is well known that the magnetic optical nonlinearity results from the nonlinear response of the magnetization in the Maxwell equation to the magnetic field of the electromagnetic waves. And the optical properties of the magnetic materials can be controlled by additional magnetic field, increasing the feasibility of artificial regulation magnetic material electromagnetic properties. AF resonance frequency region can produce many optical properties which are different from the nonmagnetic media.

In addition, the AF magnetization is influenced by the incident electromagnetic wave frequency and the strength of the electromagnetic wave as well as the AF electromagnetic strength. Thus people design many structures to use the magnetooptical properties of the ferromagnetic system; one of the most important is the presented concept of magnetic photonic crystals and magnetic multilayer [1–3] and the realization in experiment. Magnetic photonic crystals exhibit many significant properties, such as huge Faraday rotation [4], the irreversible properties of light propagation [5–10], and amplified action on the AF nonlinear effect. When photonic crystal original symmetry is damaged, the photons in the band gaps will appear in defect mode [11]; when the frequency of the electromagnetic wave is in defect mode frequency, photonic crystal appears as light local phenomenon internally and it will enhance the electromagnetic wave strength within photonic crystal.

Voigt and Faraday bit are common types of AF system for electromagnetic properties. Voigt type is the situation that AF saturation magnetization and the external static magnetic field direction are parallel to the surface of AF, while Faraday type is the situation that the saturation magnetization and static magnetic field direction are perpendicular to the surface of AF. In Faraday type, when electromagnetic waves irradiate on AF film, the transmitted light appears as the phenomenon of polarization rotation, that is, Faraday optical rotation, but the phenomenon does not appear in Voigt type. Therefore, the optical properties of the AF system are very different under different types.

The structure of the quasiperiodic photonic crystal [12] is between the orderly and disorderly systems, and its optical properties are very different from that of periodic photonic crystal. Since the Fibonacci sequence quasiperiodic superlattice [13] has been prepared in experiment, the research about quasiperiodic structure attracted some attention in recent years. At present, periodic magnetic photonic band structure and defect states have a mature theory; however, the study of quasiperiodic magnetic photonic crystals [14–17] is just starting. Because the optical properties of the magnetic materials can be controlled through additional magnetic field, the incident wave polarization method, the magnetic photonic crystals [18–20] have a good application prospect.

Many literatures have been reported about the linear and nonlinear nature of the AF periodic photonic crystal [21], but the studies about quasiperiodic photonic crystal are still few. We have studied the transmission properties of the AF quasiperiodic structure in Voigt type, which indicates the incident electromagnetic wave polarization has a great influence on the transmission nature. When TM wave irradiates, the AF magnetization is a fixed value, and the optical properties of AF and nonmagnetic dielectric layer are the same. But when TE wave irradiates, it can be observed that AF magnetization is frequency-dependent on transmission spectra. However, in the Faraday geometry AF magnetization changes with the frequency of the incident electromagnetic waves for TM and TE waves. Therefore, the optical properties are very different from the AF system in Voigt type. This paper mainly studies THz wave transmission properties in one-dimensional quasiperiodic AF/dielectric photonic crystal in Faraday type, providing theoretical support for the AF device design and processing.

2. Theoretical Model

One-dimensional Fibonacci quasiperiodic AF photonic crystal contains the AF layer (layer A) and dielectric layer (layer B). They constitute the photonic crystal according to the Fibonacci sequence alignments, with arrangement as follows: $S_1 = A$, $S_2 = AB$, $S_{j+1} = S_j S_{j-1}$, and $j \geq 2$, constituting arbitrary order for one-dimensional quasiperiodic magnetic photonic crystals followed by the iteration, and j is the progression of quasiperiodic photonic crystals.

Faraday type is the commonly used model for studying AF system. Faraday type refers to AF sublattice saturation magnetization which is perpendicular to the surface of AF, external constant magnetic field along the sublattice magnetization direction; we set the direction of the propagation as z-axis. Electromagnetic wave irradiates parallel to the x-z plane (Figure 1). A layer is magnetic layer, the thickness is d_a, the dielectric constant is ε_a, B layer is the dielectric layer, the thickness is d_1, and the dielectric constant is ε_1.

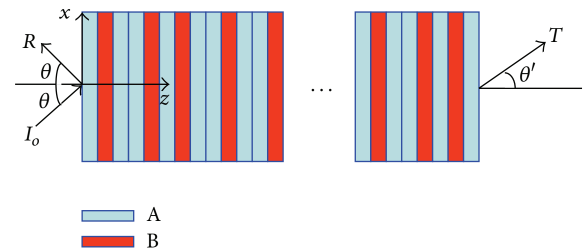

Figure 1: AF photonic crystals in Faraday geometry and coordinate system.

Magnetooptical properties of the AF come from the coupling of AF magnetization and the magnetic field component in the electromagnetic field. In the coordinate system, as shown in Figure 1, AF susceptibility can be expressed as [22]

$$\overleftrightarrow{\mu} = 1 + \overleftrightarrow{\chi} = \begin{pmatrix} 1+\chi_{xx}^{(1)} & \chi_{xy}^{(1)} & 0 \\ -\chi_{xy}^{(1)} & 1+\chi_{yy}^{(1)} & 0 \\ 0 & 0 & 1 \end{pmatrix} = \begin{pmatrix} \mu_1 & i\mu_2 & 0 \\ -i\mu_2 & \mu_1 & 0 \\ 0 & 0 & 1 \end{pmatrix}, \tag{1}$$

and here

$$\begin{aligned} \chi_{xx}^{(1)} &= \chi_{yy}^{(1)} \\ &= \omega_a' \omega_m \left\{ \frac{1}{\left[\omega_r'^2 - (\omega-\omega_0)^2\right]} + \frac{1}{\left[\omega_r'^2 - (\omega+\omega_0)^2\right]} \right\}, \\ \chi_{xy}^{(1)} &= -\chi_{yx}^{(1)} \\ &= i\omega_a' \omega_m \left\{ \frac{1}{\left[\omega_r'^2 - (\omega-\omega_0)^2\right]} - \frac{1}{\left[\omega_r'^2 - (\omega+\omega_0)^2\right]} \right\}, \end{aligned} \tag{2}$$

where $\omega_r' = [\omega_a'(2\omega_e + \omega_a')]^{1/2}$ and $\omega_a' = \omega_a - i\tau\omega$, $\omega_a = \gamma H_a$, $\omega_0 = \gamma H_0$, and $\omega_m = 4\pi\gamma M_0$. $\vec{H}_a$ is anisotropic field, $\vec{H}_e$ is exchange field, $\vec{H}_0$ is the external static magnetic field, and $\vec{M}_0$ is sublattice magnetization. ω_r is zero outside the AF resonance frequency, and γ is gyromagnetic ratio. According to the Maxwell equations, we can get the wave equation of the plane electromagnetic waves in the AF:

$$\nabla\left(\nabla \cdot \vec{H}_a\right) - \nabla^2 \vec{H}_a - \varepsilon_a \omega^2 \overleftrightarrow{\mu} \cdot \vec{H}_a = 0, \tag{3}$$

and propagation constant is $\overrightarrow{k} = (k_x, 0, k_z)$; two solutions can be obtained for k_z^2, k_1^2, and k_2^2:

$$k_1^2 = \varepsilon_a \mu_1 \omega^2 - \frac{(\mu_1+1)k_x^2}{2} + \frac{\left[(\mu_1-1)^2 k_x^4 - 4\varepsilon_a \mu_2^2 \omega^2 \left(k_x^2 - \varepsilon_a \omega^2\right)\right]^{1/2}}{2}, \quad (4a)$$

$$k_2^2 = \varepsilon_a \mu_1 \omega^2 - \frac{(\mu_1+1)k_x^2}{2} - \frac{\left[(\mu_1-1)^2 k_x^4 - 4\varepsilon_a \mu_2^2 \omega^2 \left(k_x^2 - \varepsilon_a \omega^2\right)\right]^{1/2}}{2}. \quad (4b)$$

According to (4a) and (4b), it can be seen that two wave vectors of the incident electromagnetic wave are inside the AF film; that is, birefringence phenomenon exists within the AF film. The electromagnetic field component within the AF film should be amended to

$$\overrightarrow{H}_a = \left[\overrightarrow{A}_a^{+} \exp(ik_1 z) + \overrightarrow{A}_a^{-} \exp(-ik_1 z) + \overrightarrow{B}_a^{+} \exp(ik_2 z) + \overrightarrow{B}_a^{-} \exp(-ik_2 z)\right] \exp(ik_x x - i\omega t), \quad (5)$$

and the magnetic field component $\overrightarrow{H}_a$ contains $\overrightarrow{A}_a^{\pm}$, $\overrightarrow{B}_a^{\pm}$, and a total of 12 component amplitudes, but they are not independent; by constraint relation (3), we can get $A_x^{\pm}$ and $B_x^{\pm}$ four independent amplitude of the 12 coefficient; other coefficients can be expressed as

$A_{ay}^{\pm} = \beta_1 A_{ax}^{\pm}$, $B_{ay}^{\pm} = \beta_2 B_{ax}^{\pm}$, $A_{az}^{\pm} = \pm\lambda_1 A_{ax}^{\pm}$, and $B_{az}^{\pm} = \lambda_2 B_{ax}^{\pm}$, where $\lambda_l = k_x k_l/(k_x^2 - \varepsilon_a \mu_0 \omega^2)$, $\beta_l = i\varepsilon_a \mu_2 \omega^2/(\varepsilon_a \mu_1 \omega^2 - k_x^2 - k_l^2)$, $l = 1$ or 2. Expression of the magnetic field strength in the layers of dielectric is

$$\overrightarrow{H} = \begin{cases} \left[\overrightarrow{I} \exp(ik_x x) + \overrightarrow{R} \exp(-ik_x x)\right] \exp(ik_{tz} z) & \text{the incident medium} \\ \left[\overrightarrow{A} \exp(ik_x x) + \overrightarrow{B} \exp(-ik_x x)\right] \exp(ik_{1z} z) & \text{the dielectric layer} \\ \overrightarrow{T} \exp(ik_x x) \exp(ik_{bz} z) & \text{the transmission medium.} \end{cases} \quad (6)$$

When the electromagnetic wave propagates in the dielectric, the relationship between the propagation constants is $H_{jz} = -(k_x/k_{jz})H_{jx} = \eta_j H_{jx}$, $j = t, 1, b$ corresponding to the incident medium, the dielectric layer, and transmission medium, respectively. Based on the boundary conditions of electromagnetic field, the transfer matrix between the layers can be expressed as follows. The transfer matrix between the media above system and AF is

$$\begin{pmatrix} I_x \\ R_x \\ I_y \\ R_y \end{pmatrix} = T_{ta} \begin{pmatrix} A_{ax}^{+} \\ A_{ax}^{-} \\ B_{ax}^{+} \\ B_{ax}^{-} \end{pmatrix}, \quad (7)$$

where

$$T_{ta} = \frac{1}{2} \begin{pmatrix} 1+\Gamma_{t1} & 1-\Gamma_{t1} & 1+\Gamma_{t2} & 1-\Gamma_{t2} \\ 1-\Gamma_{t1} & 1+\Gamma_{t1} & 1-\Gamma_{t2} & 1+\Gamma_{t2} \\ \beta_1(1+\delta_{t1}) & \beta_1(1-\delta_{t1}) & \beta_2(1+\delta_{t2}) & \beta_2(1-\delta_{t2}) \\ \beta_1(1-\delta_{t1}) & \beta_1(1+\delta_{t1}) & \beta_2(1-\delta_{t2}) & \beta_2(1+\delta_{t2}) \end{pmatrix},$$

$$\Gamma_{tl} = \frac{\varepsilon_t (k_x \lambda_l - k_l)}{\varepsilon_a (k_x \eta_t - k_{tz})}, \quad \delta_{tl} = \frac{\varepsilon_t k_l}{\varepsilon_a k_{tz}}, \quad l = 1 \text{ or } 2. \quad (8)$$

The transfer matrix between dielectric layer and the ferromagnetic layers is

$$\begin{pmatrix} A_{1x} \\ B_{1x} \\ A_{1y} \\ B_{1y} \end{pmatrix} = T_{1a} \begin{pmatrix} A_{ax}^{+} \\ A_{ax}^{-} \\ B_{ax}^{+} \\ B_{ax}^{-} \end{pmatrix}, \quad (9)$$

where

$$T_{1a} = \frac{1}{2} \begin{pmatrix} \delta_1^{-1} & \delta_1^{-1} & 0 & 0 \\ \delta_1 & -\delta_1 & 0 & 0 \\ 0 & 0 & \delta_1^{-1} & \delta_1^{-1} \\ 0 & 0 & \delta_1 & -\delta_1 \end{pmatrix} \times \begin{pmatrix} 1 & 1 & 1 & 1 \\ \Gamma_{11} & -\Gamma_{11} & \Gamma_{12} & -\Gamma_{12} \\ \beta_1 & \beta_1 & \beta_2 & \beta_2 \\ \delta_{11}\beta_1 & -\delta_{11}\beta_1 & \delta_{12}\beta_2 & -\delta_{12}\beta_2 \end{pmatrix}, \quad (10)$$

$$\delta_1 = \exp(ik_{1z} d_1), \quad \delta_{1l} = \frac{\varepsilon_1 k_l}{\varepsilon_a k_{1z}},$$

$$\Gamma_{1l} = \frac{\varepsilon_1 (k_x \lambda_l - k_l)}{\varepsilon_a (k_x \eta_b - k_{bz})}, \quad l = 1 \text{ or } 2.$$

The transfer matrix between ferromagnetic layers and the dielectric layers is

$$\begin{pmatrix} A_{ax}^{+} \\ A_{ax}^{-} \\ B_{ax}^{+} \\ B_{ax}^{-} \end{pmatrix} = T_{a1} \begin{pmatrix} A_{1x} \\ B_{1x} \\ A_{1y} \\ B_{1y} \end{pmatrix}, \quad (11)$$

where

$$T_{a1} = \begin{pmatrix} -\Lambda_\beta \beta_2 \delta_{a1}^{-1} & \Lambda \delta_{j2} \beta_2 \delta_{a1}^{-1} & \Lambda_\beta \delta_{a1}^{-1} & -\Lambda_j \Gamma_{j2} \delta_{a1}^{-1} \\ -\Lambda_\beta \beta_2 \delta_{a1} & -\Lambda \delta_{j2} \beta_2 \delta_{a1} & \Lambda_\beta \delta_{a1} & \Lambda_j \Gamma_{j2} \delta_{a1} \\ \Lambda_\beta \beta_1 \delta_{a2}^{-1} & -\Lambda \delta_{j1} \beta_1 \delta_{a2}^{-1} & -\Lambda_\beta \delta_{a2}^{-1} & \Lambda_j \Gamma_{j1} \delta_{a2}^{-1} \\ \Lambda_\beta \beta_1 \delta_{a2} & \Lambda \delta_{j1} \beta_1 \delta_{a2} & -\Lambda_\beta \delta_{a2} & -\Lambda_j \Gamma_{j1} \delta_{a2} \end{pmatrix} \times \begin{pmatrix} 1 & 1 & 0 & 0 \\ 1 & -1 & 0 & 0 \\ 0 & 0 & 1 & 1 \\ 0 & 0 & 1 & -1 \end{pmatrix},$$

$$\delta_{1l} = \frac{\varepsilon_1 k_l}{\varepsilon_a k_{1z}}, \quad \Gamma_{1l} = \frac{\varepsilon_1 (k_x \lambda_l - k_l)}{\varepsilon_a (k_x \eta_1 - k_{1z})},$$

$$\Lambda_\beta = \frac{1}{2(\beta_1 - \beta_2)}, \quad \Lambda = \frac{1}{2(\Gamma_{11}\delta_{12}\beta_2 - \Gamma_{12}\delta_{11}\beta_1)},$$

$$\delta_{al} = \exp(ik_l d_a), \quad l = 1 \text{ or } 2. \quad (12)$$

Transitive relation of the boundary amplitude between the dielectric layer and the below space is

$$\begin{pmatrix} A_{1x} \\ B_{1x} \\ A_{1y} \\ B_{1y} \end{pmatrix} = T_{1b} \begin{pmatrix} T_x \\ 0 \\ T_y \\ 0 \end{pmatrix}, \tag{13}$$

where

$$T_{1b} = \frac{1}{2} \begin{pmatrix} 1+\frac{1}{\Gamma_{1b}} & 1-\frac{1}{\Gamma_{1b}} & 0 & 0 \\ 1-\frac{1}{\Gamma_{1b}} & 1+\frac{1}{\Gamma_{1b}} & 0 & 0 \\ 0 & 0 & 1+\frac{1}{\delta_{1b}} & 1-\frac{1}{\delta_{1b}} \\ 0 & 0 & 1-\frac{1}{\delta_{1b}} & 1+\frac{1}{\delta_{1b}} \end{pmatrix},$$

$$\delta_{1b} = \frac{\varepsilon_1 k_{bz}}{k_{1z}\varepsilon_b}, \quad \Gamma_{1b} = \frac{\varepsilon_1 (k_x \eta_b - k_{bz})}{\varepsilon_b (k_x \lambda_1 - k_{1z})}. \tag{14}$$

The transfer relationship between amplitudes can be gotten through the boundary continuity of AF layer and medium below system:

$$\begin{pmatrix} A_{ax}^+ \\ A_{ax}^- \\ B_{ax}^+ \\ B_{ax}^- \end{pmatrix} = T_{ab} \begin{pmatrix} T_x \\ 0 \\ T_y \\ 0 \end{pmatrix}, \tag{15}$$

where

$$T_{ab} = \frac{1}{2\Lambda} \begin{pmatrix} \delta_{21}^+ & \delta_{21}^- & \Delta_{12}^- & \Delta_{12}^+ \\ \delta_{21}^- & \delta_{21}^+ & \Delta_{12}^+ & \Delta_{12}^- \\ \delta_{12}^+ & \delta_{12}^- & \Delta_{21}^- & \Delta_{21}^+ \\ \delta_{12}^- & \delta_{12}^+ & \Delta_{21}^+ & \Delta_{21}^- \end{pmatrix}, \quad \delta_{al} = \exp(ik_l d_a),$$

$$\Gamma_{bl} = \frac{\varepsilon_b (k_x \lambda_l - k_l)}{\varepsilon_a (k_x \eta_b - k_{bz})}, \quad \delta_{bl} = \frac{\varepsilon_b k_l}{\varepsilon_a k_{bz}},$$

$$\Lambda_\beta = \frac{1}{2(\beta_1 - \beta_2)}, \quad \Lambda_b = \frac{1}{2(\Gamma_{b1}\delta_{b2}\beta_2 - \Gamma_{b2}\delta_{b1}\beta_1)},$$

$$\Lambda = (\beta_{b1} - \beta_{b2})(\Gamma_{b2}\delta_{b1}\beta_{b1} - \Gamma_{b1}\delta_{b2}\beta_{b2}),$$

$$\Delta_{ij}^\pm = (\delta_{bi} + 1)\Gamma_{bj}\beta_{bi} - \beta_{bj}(\Gamma_{bj} + \Gamma_{bi}\delta_{bj}),$$

$$\delta_{ij}^\pm = \beta_{bi}\left[(\Gamma_{bj} + 1)\delta_{bi}\beta_{bi} - \beta_{bj}(\delta_{bi} + \Gamma_{bi}\delta_{bj})\right],$$

$$\text{here } i, j = 1 \text{ or } 2, \quad i \neq j. \tag{16}$$

Using the method of transfer matrix, we can get the relations of amplitude between incident electromagnetic wave and transmission electromagnetic waves:

$$\begin{pmatrix} I_x \\ R_x \\ I_y \\ R_y \end{pmatrix} = \prod \begin{pmatrix} T_x \\ 0 \\ T_y \\ 0 \end{pmatrix}, \tag{17}$$

where $\prod$ is the transfer matrix of quasiperiodic photonic crystals. According to (17), the pump wave transmission and reflection amplitude component can be expressed as follows:

$$T_x = \frac{(\Pi_{33} I_x - \Pi_{13} I_y)}{(\Pi_{11}\Pi_{33} - \Pi_{13}\Pi_{31})}, \tag{18a}$$

$$T_y = \frac{(\Pi_{11} I_y - \Pi_{31} I_x)}{(\Pi_{11}\Pi_{33} - \Pi_{13}\Pi_{31})}, \tag{18b}$$

$$T_z = \eta_b T_x, \tag{18c}$$

$$R_x = \Pi_{31} T_x + \Pi_{33} T_y, \tag{18d}$$

$$R_y = \Pi_{41} T_x + \Pi_{43} T_y, \tag{18e}$$

$$R_z = \eta_t R_x, \tag{18f}$$

and the reflection amplitude of the pump wave is

$$|R|^2 = |R_x|^2 + |R_y|^2 + |R_z|^2. \tag{19a}$$

The transmission amplitude of the pump wave is

$$|T|^2 = |T_x|^2 + |T_y|^2 + |T_z|^2. \tag{19b}$$

According to (19a) and (19b), the transmission and reflection amplitude of the pump wave can be obtained. We can analyze transport properties and photonic band structure of electromagnetic waves according to the transmittance of quasiperiodic photonic crystal.

3. Numerical Simulation and Discussion

We take the typical AF material MnF_2 as an example where the relevant physical parameters are listed as follows: exchange field $H_e = 550$ kG, anisotropic field $H_a = 7.87$ kG, sublattice magnetization $M_0 = 0.6$ kG, gyromagnetic ratio $\gamma = 1.97 \times 10^{10}$ rads^{-1} kG^{-1}, and relative dielectric constant $\varepsilon_c = 5.5$ [22]. When the external static magnetic field $H_0 = 1.0$ kG, the two antiferromagnetic resonance frequency is $\omega_1/2\pi c = 9.76\,\text{cm}^{-1}$ and $\omega_2/2\pi c = 9.83\,\text{cm}^{-1}$. AF damping coefficient is $\tau = 0.001$, and thickness is $d_a = 255\,\mu$m. Dielectric material is SiO_2, dielectric constant is 2.3, and thickness is $d_1 = 105.7\,\mu$m. Both sides of photonic crystal are air. In the following, we will study the influence of electromagnetic wave polarization, the series of quasiperiodic photonic crystals, the applied static magnetic field, and the dielectric layer on the transport properties of AF quasiperiodic photonic crystal.

In Faraday type, photonic crystal rotates symmetrically along the z-axis. When the electromagnetic wave irradiates perpendicularly, the electric field and magnetic field of TE wave (horizontal waves) and TM wave (horizontal magnetic wave) are both parallel to photons crystal surface which are equivalent on physical properties. When electromagnetic wave irradiates obliquely, TE and TM waves are in the incident medium, and the magnetic field components are

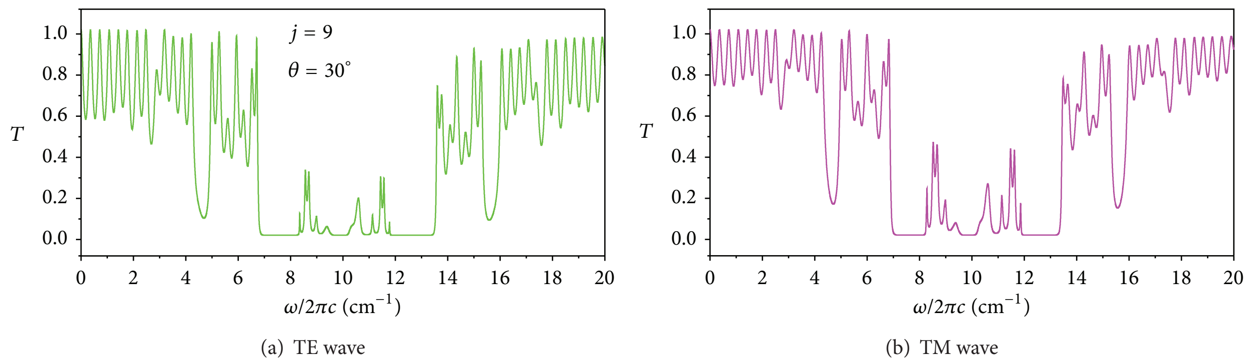

FIGURE 2: The transmission spectra of the incident TE wave (a) and TM wave (b).

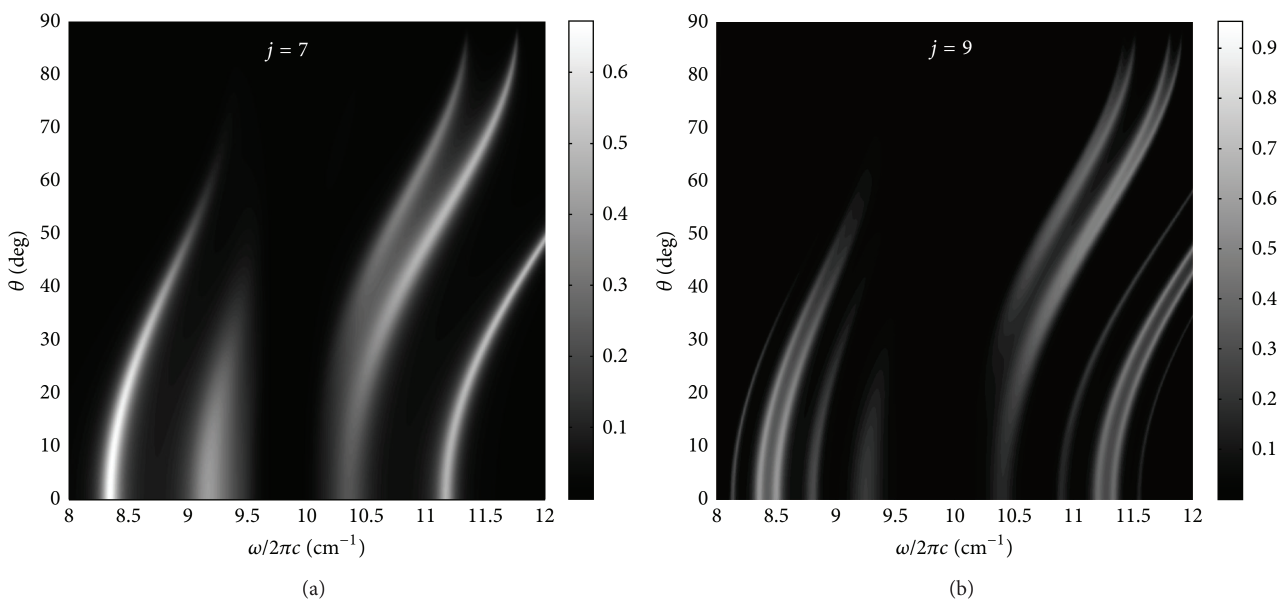

FIGURE 3: When TE wave oblique incident; the transmission spectra of AF photonic crystals with the different series: (a) $j = 7$, (b) $j = 9$.

$(h_x, 0, h_z)$ and $(0, h_y, 0)$, respectively. However, the magnetic field components in the AF media are (h_x, h_y, h_z) and $(h_x, h_y, 0)$, respectively. Electromagnetic wave of different polarization is different in the AF magnetization, so the nature of spreading in the AF medium is different. At first, we explore the transmission spectrum of TE and TM wave in a photonic crystal. Figure 2 shows the transmission spectra of electromagnetic wave with 30° incident angle to nine quasiperiodic photonic crystals.

When electromagnetic waves incident angle is 30°, no matter either TM or TE wave irradiate, there exist obvious completely photonic band gaps around the frequency of $7.0{\sim}8.0\,\mathrm{cm}^{-1}$ and $12{\sim}13.5\,\mathrm{cm}^{-1}$ and AF resonance frequency of $9.8\,\mathrm{cm}^{-1}$, and there are double bifurcation structures in transmission peak in the frequency of $8.5{\sim}9.5\,\mathrm{cm}^{-1}$ and $10{\sim}12\,\mathrm{cm}^{-1}$ range. We can take advantage of this nature to achieve the filter. A strong resonance absorption will happen near the AF resonance frequency, so the intensity of the AF resonance frequency near the transmission peak is not very high. Away from the AF resonance frequency region, AF susceptibility is approximately equal to 1; it is the same as the magnetic susceptibility of the nonmagnetic media. Therefore, the transmission spectrums of TE and TM wave are similar.

The transmission spectra of quasiperiodic photonic crystal were affected by the photonic crystal series and the incident angle. Figures 3 and 4 give the transmission spectra of TE and TM waves in the seventh and ninth level photonic crystal, respectively. The horizontal axis is the frequency of the incident electromagnetic wave, the longitudinal axis is the incident angle of electromagnetic wave, and color depth represents the strength of the transmission peak. We mainly study the influence of AF alignment on transmission spectrum of the periodic photonic crystal, so frequency ranges are in the vicinity of the AF resonance frequency

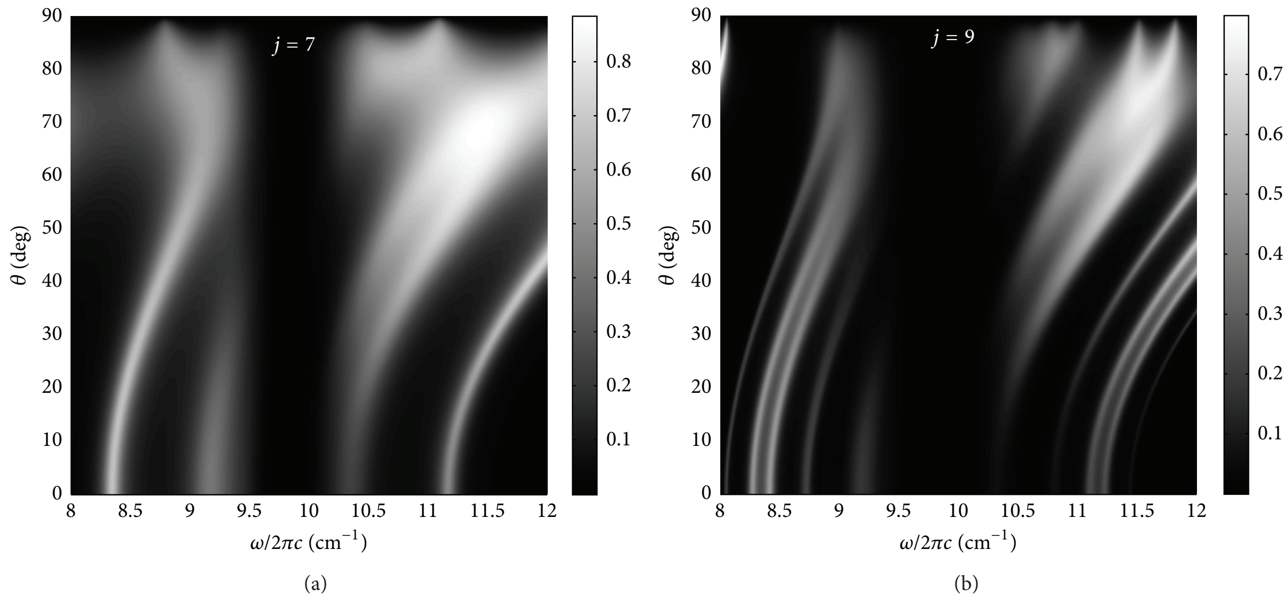

Figure 4: When TM wave irradiates obliquely, the transmission spectra of AF photonic crystals with the different series: (a) $j = 7$, (b) $j = 9$.

(Figures 3 and 4). No matter how the polarization of the incident electromagnetic wave is, transmission peaks move to high frequency direction with the increase of incident angle. And the incident area of TE wave transmission peaks is significantly less than that of the incident TM wave transmission peak.

When series of photonic crystal is small, the number of layers in photonic crystal is few, and small incident angle of transmission peak is relatively wide, but bifurcate structure appears when incident angle is big. With the increase in the series of photonic crystal, the transmission peaks become sharper, double bifurcation structure is more obvious, the number of layers of photonic crystal becomes larger, the number of AF increases, and the intensity of AF resonance absorption also becomes stronger. It can be found that in the transmission spectrum the area of lower transmission intensity gradually expanded around the AF resonance frequency.

External static magnetic field also has a certain impact on transmission properties of the AF quasiperiodic photonic crystal. According to expression (1) of the AF susceptibility, we can draw conclusion that the AF resonance frequency spacing increases with increase of H_0. By calculation without external magnetic field $H_0 = 0$, the corresponding AF resonance frequency is only one: $\omega/2\pi c = 9.7588\,\text{cm}^{-1}$; when $H_0 = 6\,\text{kG}$, the two AF resonance frequencies are $10.3858\,\text{cm}^{-1}$ and $9.1325\,\text{cm}^{-1}$. Figure 5 shows the transmission spectra of the ninth quasiperiodic photonic crystals under different applied static magnetic field. Without external magnetic field, all polarized lights irradiate in the vicinity of the AF resonance frequency of $\omega/2\pi c = 9.7588\,\text{cm}^{-1}$. There is a wide range of forbidden bands; but with the strength of external magnetic field increasing, the forbidden bandwidth reduces gradually, and when $H_0 = 6\,\text{kG}$, no obvious forbidden band appears. In order to explain the phenomenon, Figure 6 shows the trend of the imaginary part of AF conductivity μ_1 changes with the external magnetic field and the frequency of the incident wave. The imaginary part of permeability corresponds to the loss energy per unit time. Without external magnetic field, the resonance frequency of the AF is only one; with the increased intensity of the applied magnetic field, the AF resonance frequency splits into two, but the imaginary part of corresponding magnetic conductance drops gradually; that is, the corresponding loss gradually reduced. So without an external magnetic field, there exists relatively wide band gap in the transmission spectra.

4. Summary

In this paper, the transfer matrix method is used to study the transmission properties of MnF_2/SiO_2 quasiperiodic photonic crystal in Faraday type. MnF_2 layer and SiO_2 layers are arranged alternately to constitute the structure of the Fibonacci sequence quasiperiodic photonic crystals. According to the simulation results, we found that the electromagnetic wave polarization has important influence on transmission spectrum of photonic crystal. The half-peak width of TE wave transmission peak is much smaller than that of the incident TM wave. No matter what polarization wave is, with the increase of the incident angle of electromagnetic wave, the transmission peaks move to high frequency direction. When external static magnetic field is small, there is a wide photonic band gap near the AF resonance frequency, but with the strength of external magnetic field increasing, the band gap

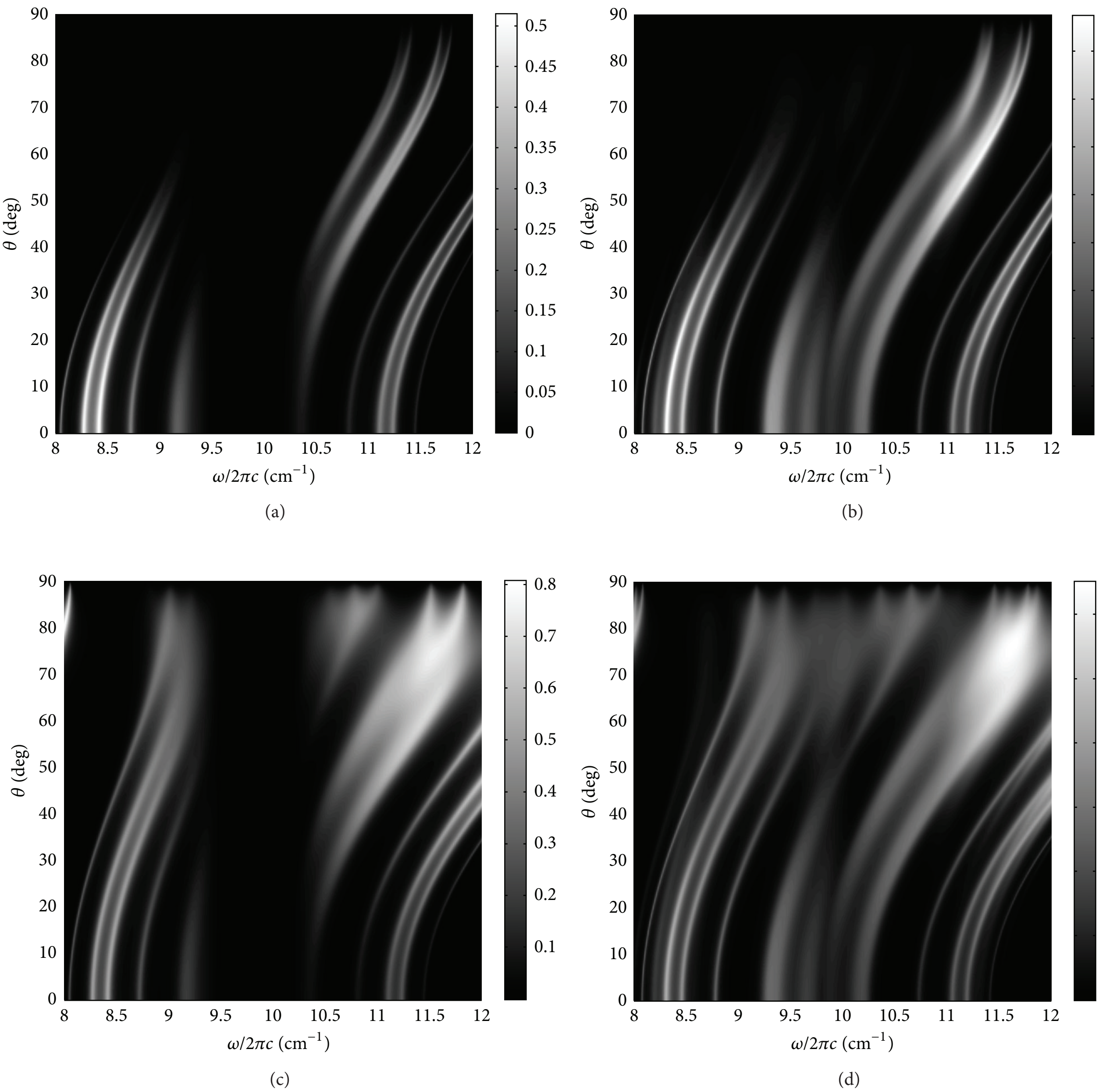

Figure 5: The transmission spectra of AF photonic crystals with $j = 9$. (a) TE wave incident, $H_0 = 0$; (b) TE wave incident, $H_0 = 6$ kG; (c) TM wave incident, $H_0 = 0$; (d) TM wave incident, $H_0 = 6$ kG.

range is gradually shrinking. With the increase in the series of photonic crystals, the double bifurcation structure appears in photonic band gap transmission peak. The transmission properties of THz waves in the AF quasiperiodic photonic crystal can be used to design multichannel filter, frequency selection, and so forth, which can achieve optical switching by controlling the external field and the incident angle changes. The combination of magnetic and photocatalytic properties enables a rapid photocatalysis recovery without an external energy supply, as well as the potential application of solar energy for water treatment and disinfection processes.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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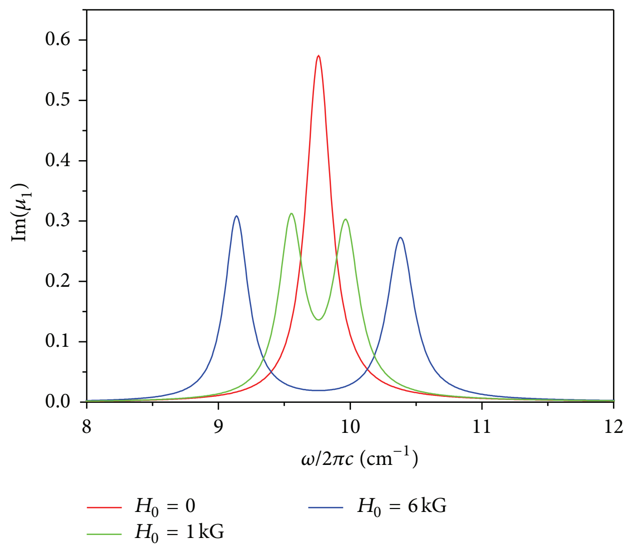

Figure 6: The imaginary part of AF permeability μ_1 changes with the external magnetic field and incident wave frequency.

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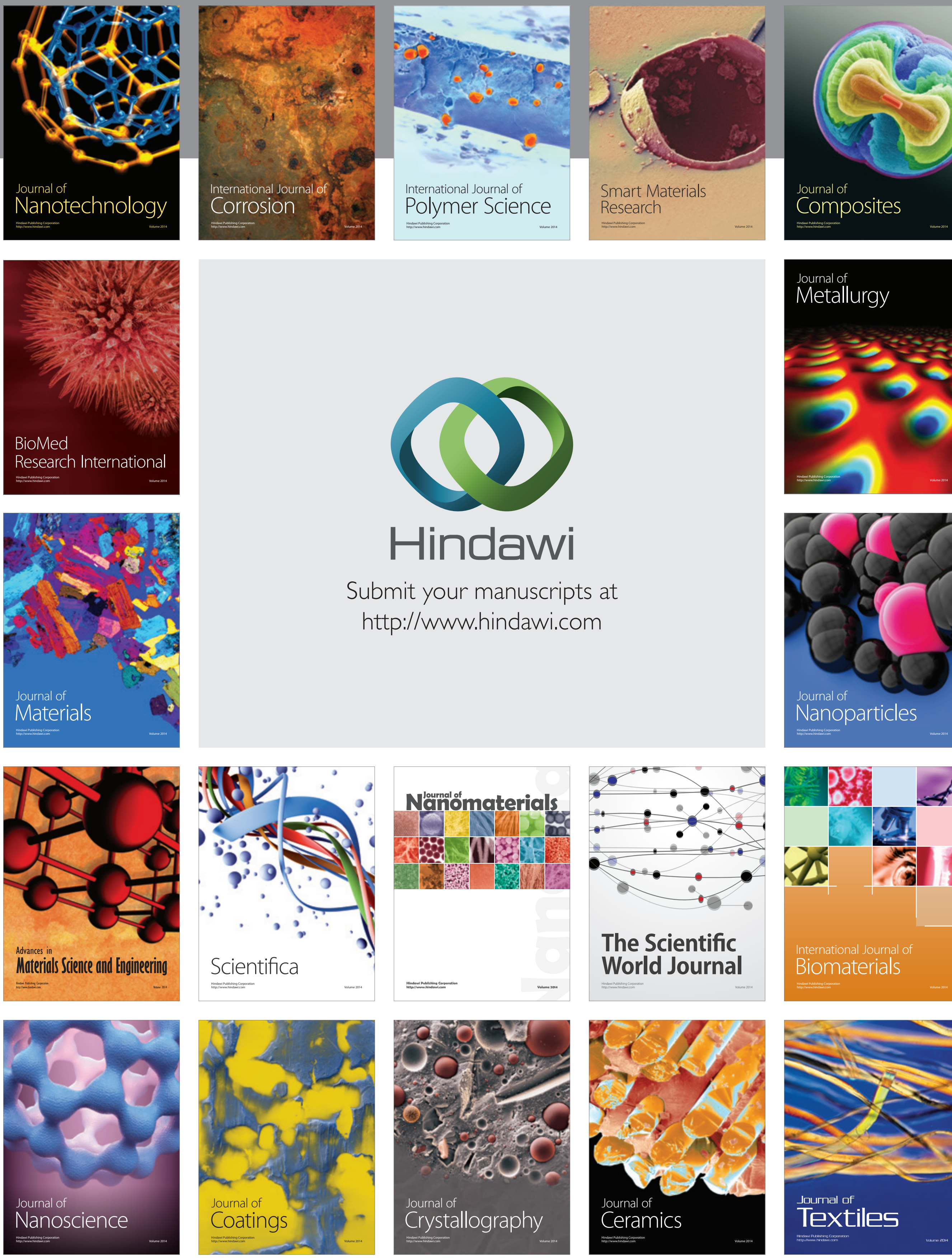
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