Research on Structural Color Contact Lenses Based on Magnetically Controlled Photonic Crystals

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Abstract: In this paper, Fe3O4 nanoparticles were prepared by solvothermal method, and the morphology, magnetic properties and potential of the particles were characterized. By applying magnetic fields of different strengths, the Fe3O4 particles self-assemble into an ordered structure to construct a magneto-responsive photonic crystal, and obtain different structural colors. The HEMA copolymer hydrogel was prepared by the ultraviolet polymerization method, and the structured color contact lenses was prepared by locking the chain-like photonic crystal structure of Fe3O4 particles by the hydrogel under the combined action of a magnetic field and ultraviolet light.

1. Introduction

Structural color is a way of color presentation that is different from pigment color. It is the color produced by physical effects such as interference, diffraction or scattering of light of different wavelengths by the structure of the object itself[1]. According to the mechanism of structural color generation, researchers in the field of optics invented photonic crystals. The concept of photonic crystals was independently proposed by S. John and E. Yablonovitch in 1987[2-3], it refers to an artificial periodic dielectric structure with Photonic Band-Gap (PBG) characteristics. Responsive photonic crystals refer to photonic crystals with adjustable photonic band gap under external stimuli (including pH value, temperature, pressure, magnetic field, electric field, etc.)[4]. Magnetically responsive photonic crystals are a hot spot in the research of responsive photonic crystals. Magnetic nanoparticles can self-assemble into an ordered structure under the action of a magnetic field, and the position of the photonic band gap can also be adjusted by changing the strength of the magnetic field. In the construction of magneto-responsive photonic crystals, Fe_3O_4 particles are the most widely used[5]. Fe_3O_4 nanoparticles have an important position in biomedicine, magnetic fluid, catalyst carrier, data storage and other applications due to their unique superparamagnetism and high biological safety.[6-8]At present, most of the color contact lenses on the market achieve color development by mixing pigments in the lens. Once the lens is broken, the pigment contacts the cornea and conjunctiva, which will easily cause ocular surface lesions. Therefore, it is of great significance and value to use structural color to replace pigment color. In this paper, Fe_3O_4 nanoparticles are used to construct magnetically responsive photonic crystals, and different structural colors are obtained through magnetic field control. The chain-like photonic crystal structure formed by polymer hydrogel locking and self-assembly is used to achieve the fixation of structural colors.

2. Experiment

2.1 Reagents and Instruments

Reagents:Polyvinylpyrrolidone(PVP-K30), D(+) glucose, Ethylene glycol, Ferric Chloride Hexahydrate, Sodium acetate(NaAc), Absolute ethanol, Hydroxyethyl methacrylate(HEMA), 2-hydroxy-2-methyl-1-phenyl-1-acetone(HMPP),

Ethylene glycol dimethacrylate(EGDMA)

Instruments:electronic balance, heated magnetic stirrer, vacuum drying oven, ultrasonic cleaner,

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transmission electron microscope, particle size analyzer, vibrating sample magnetometer, ultraviolet light source

2.2 Preparation of Fe3o4 Nanoparticles by Solvothermal Method

Add 3.33g PVP-K30, 0.32g glucose and 30ml ethylene glycol to a 50ml round-bottomed flask. Heat it in an oil bath at 100°C while magnetically stirring for 10min. Cool to room temperature and observe that the reactants are completely dissolved, then add 0.675g $FeCl_3.6H_2O$ and stir. 30min, then add 3.28g NaAc and stir for 40min until the reactants in the flask are completely dissolved, pour the solution into a polytetrafluoroethylene lining and put it into a high-temperature reaction kettle, place it in a vacuum drying oven at 200°C for 10h, after the reaction is over, it will naturally Cool to room temperature, disperse the product in ethanol, repeatedly clean the product with ethanol with the help of an external magnetic field, and disperse the product ultrasonically for 30 minutes[9].

2.3 Magnetic Field Control Structure Color

Disperse Fe_3O_4 particles evenly in ethanol, add a 40*20mm solid circular magnet, change the distance between the magnet and the particles to observe the color change and measure the reflectance with a fiber optic spectrometer, while measuring the magnetic field strength at each site with a magnetometer.

2.4 Preparation of Structured Color Contact Lenses

Disperse Fe_3O_4 particles evenly in 1ml HEMA, add 20μl of HMPP and 10μl of EGDMA, ultrasonic for 20min to mix evenly, take 100μl of the mixed solution and drop it into the concave mold of the conta1ct lens mold, and fasten the convex mold cover to isolate the lens material from air and apply a magnetic field. Uniform magnetic field with intensity of 350Gs, UV light for 3min[10].

3. Results and Discussion

3.1 Fe_3o_4 Particle Characterization and Result Discussion

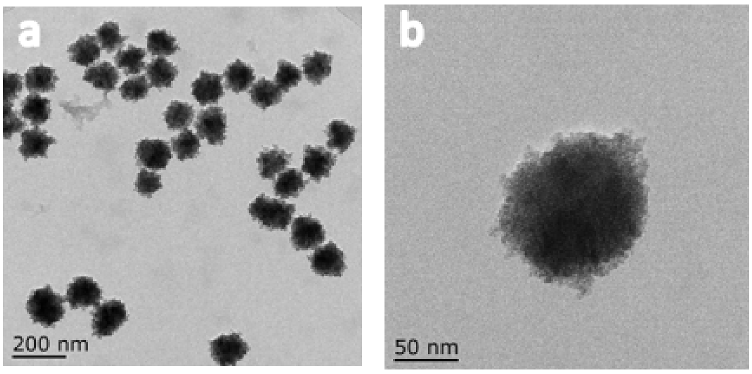

Fig.1 Fe_3o_4 Particle Transmission Electron Microscope

It can be seen from Figure1 that the Fe_3O_4 particles are black solid spheres, the surface is not smooth, the particles are evenly dispersed, and the particle size is relatively uniform. It can be reasonably inferred that when alkaline NaAc is used under hydrothermal conditions, some Fe^{3+} ions are reduced to Fe^{2+} ions by ethylene glycol and then combined with Fe^{3+}. After the subsequent co-precipitation reaction and dehydration, it is transformed into primary Fe_3O_4 nanoparticles. Due to the strong hydrogen bonds between the glucose derivatives coated on the primary nanoparticles, the primary Fe_3O_4 nanoparticles quickly agglomerated to form clusters. At the same time, PVP will be absorbed to the surface of the cluster spontaneously, through the formation of hydrogen bonds between the negatively charged O and N in the PVP and the hydroxyl and carboxyl groups of the glucose derivative on the Fe_3O_4 cluster to generate a steric hindrance layer. This prevents further coalescence of Fe_3O_4 clusters and forms uniform Fe_3O_4@PVP particles.

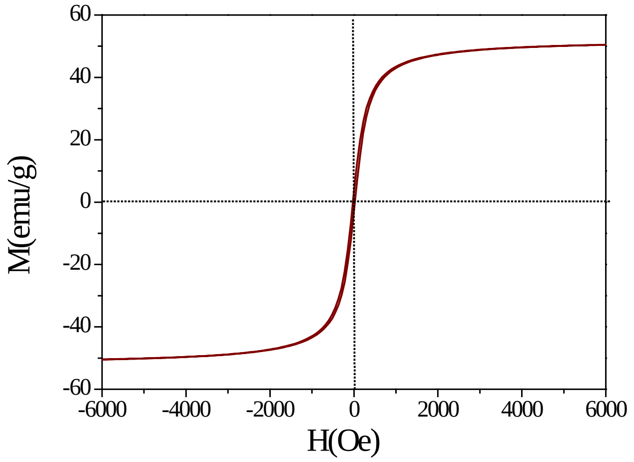

Fig.2 Fe_3o_4particle Hysteresis Loop

The hysteresis loop represents the closed magnetization curve of the hysteresis phenomenon of ferromagnetic materials when the magnetic field intensity changes periodically. It shows the relationship between the magnetization M and the magnetic field H in the process of repeated magnetization of a ferromagnetic substance. Saturation magnetization refers to the maximum magnetization that a magnetic material can reach when it is magnetized in an external magnetic field. It is an extremely important magnetic parameter for permanent magnetic materials. The hysteresis loop of Fe_3O_4 particles was measured at room temperature. Figure2 shows that the saturation magnetization (Ms) of Fe_3O_4 particles is 51.64emu/g at a temperature of 300 K. The hysteresis loop passes through the origin and the coercivity is zero, which proves that the synthesized Fe_3O_4 nanoparticles are superparamagnetic.

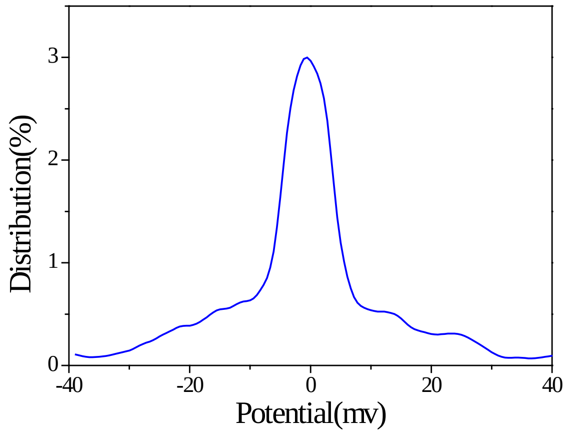

Fig.3 Fe_3o_4particle Surface Potential

Zeta potential is a measure of the strength of mutual repulsion or attraction between particles. The smaller the dispersed particles, the higher the absolute value (positive or negative) of the Zeta potential, and the more stable the system, that is, the dissolution or dispersion can resist aggregation. Conversely, the lower the Zeta potential (positive or negative), the more prone to aggregation, that is, the attractive force exceeds the repulsive force, the dispersion is destroyed and aggregation occurs. Figure3 shows that the average potential of Fe_3O_4 particles is -1.1mv.

3.2 Magnetic Field Control Structure Color Characterization and Result Discussion

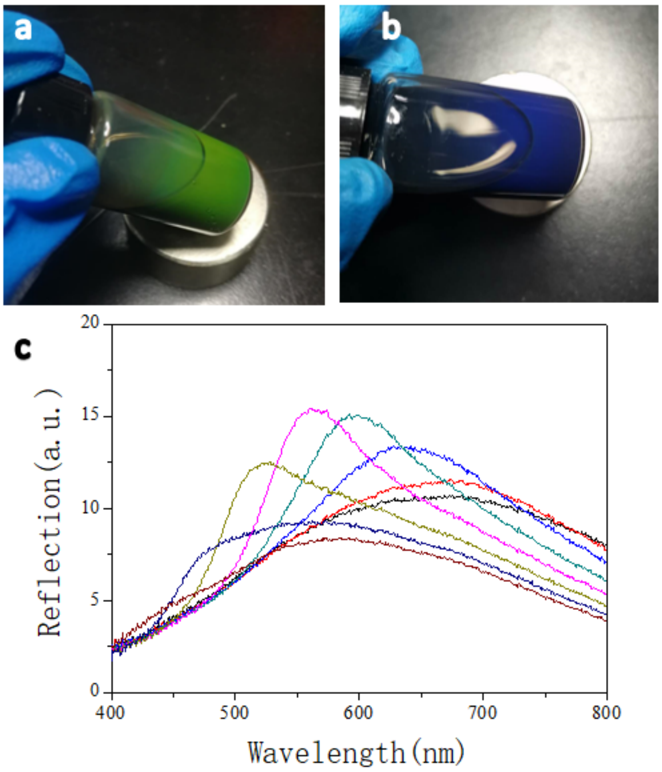

Figure4 a b The color characterization of Fe_3O_4 particles dispersed in ethanol under the action of a magnetic field, c Spectra of Fe_3O_4 particles dispersed in ethanol under different magnetic field strengths

It can be seen from Figure4 c that as the magnetic field intensity increases, the reflection peak blue shifts from 650 nm to 500 nm, and the reflection peak changes from gentle to steep and then gentle. When the magnetic field intensity is 430 Gs, the color of the particles appears green (Figure4 a), when the magnetic field intensity is 550Gs, the particle color appears blue (Figure4 b). The reason is that the change of magnetic field intensity changes the distance between Fe_3O_4 particles, and the width of the photonic band gap is different and light of different wavelengths is reflected.

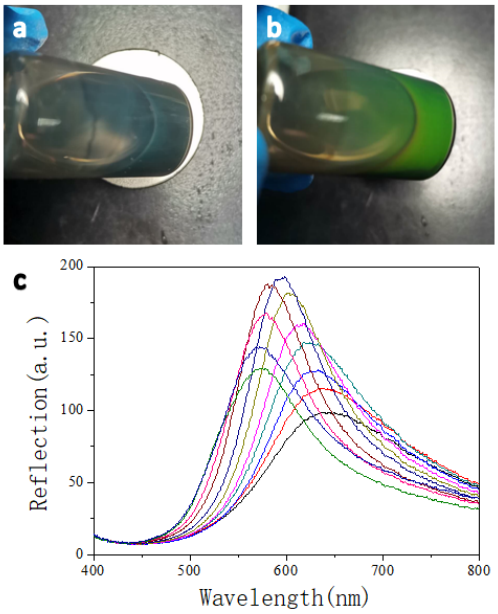

Figure5 a b The color characterization of Fe_3O_4 particles dispersed in HEMA under the action of magnetic field, c The spectra of Fe_3O_4 particles dispersed in HEMA under different magnetic field strengths

It can be seen from Figure5 c that as the magnetic field intensity increases, the reflection peak shifts from 650 nm to 570 nm. When the magnetic field intensity is 390 Gs, the particle color appears green (Figure5 a). When the magnetic field intensity is 480 Gs, The color of the particles is blue (Figure5 b). Compared with ethanol as a dispersant, the response speed of Fe_3O_4 particles under the action of a magnetic field becomes slower when dispersed in HEMA. The reason is that the HEMA mixture is more viscous and the particles migrate slower in it than in ethanol.

3.3 Structural Color Contact Lens Characterization and Result Discussion

Fig.6 Structured Color Contact Lenses

Figure 6 shows that the main body of the structural color contact lens is green, and some areas on the edge are unevenly colored orange. The diameter is 14mm, the surface is smooth, the texture is soft, and there is a certain degree of toughness. Due to the uneven magnetic field, the Fe_3O_4 particles are still moving during the polymerization process. This results in uneven location distribution and uneven color.

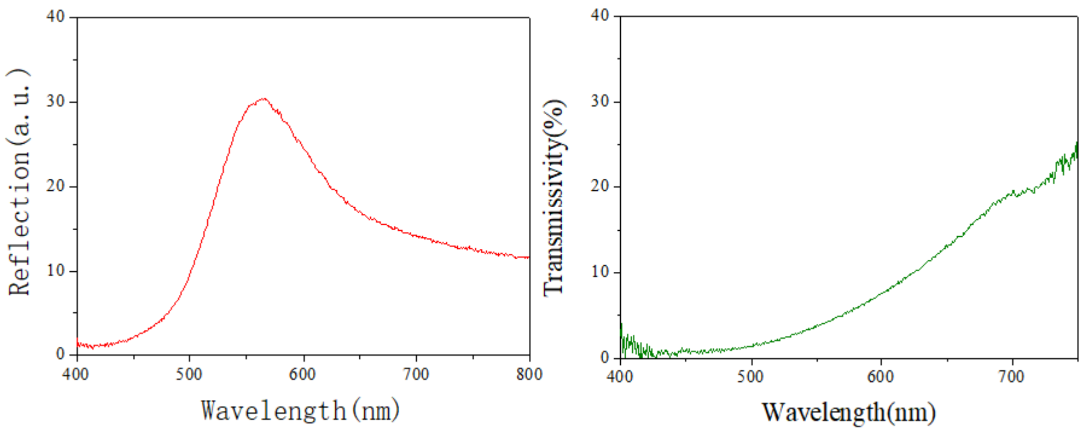

Fig.7 Reflectance and Transmittance of Structural Color Contact Lenses

A fiber optic spectrometer was used to detect the reflectance and transmittance of the structured color contact lens. As can be seen from Figure7, the peak reflection wavelength of the structured color contact lens is at 560nm; the transmittance of the structured color contact lens is in the visible light range. An upward trend, up to 20%.

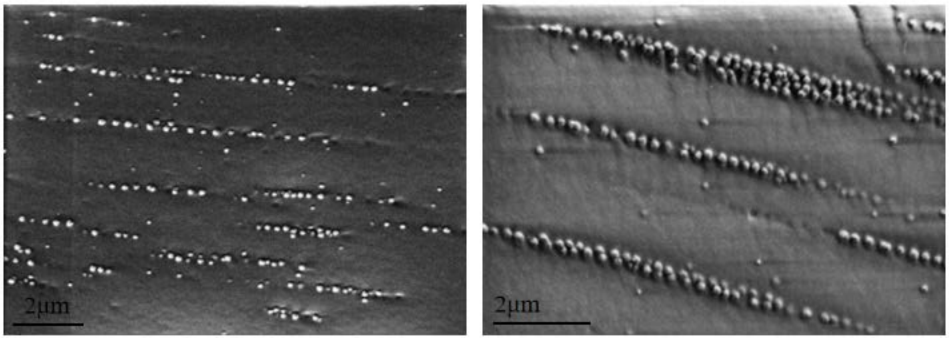

Fig.8 Structured Color Contact Lens Cross-Section Scanning Electron Microscope

From the scanning electron microscope results in Figure8, it can be seen that the Fe_3O_4 particles are solid spheres with uniform particle size. Most of the particles are fixed in the hydrogel and arranged in a chain shape. The distance between the rows is not uniform, and there are a few scattered particles. This proves that the Fe_3O_4 particles can quickly self-assemble into an ordered structure under the action of a magnetic field. As the hydrogel polymerizes, the chain-like ordered structure of the Fe_3O_4 particles is also fixed, forming a photonic band gap, resulting in structural color.

4. Conclusion

In this paper, a solvothermal method was used to prepare superparamagnetic Fe_3O_4 nanoparticles, which self-assembled into an ordered structure under the action of a magnetic field. The structural color of Fe_3O_4 particles can be adjusted by changing the magnetic field strength, and the Fe_3O_4 particles are uniformly dispersed in the HEMA mixture. The part is placed in a contact lens mold, a magnetic field is applied and the photonic crystal structure is fixed by ultraviolet light polymerization to realize the color curing, thereby preparing structured color contact lenses, which can be applied to structured color contact lenses in combination with existing contact lens manufacturing technology In research and production.

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