The Development of Color Display Technology

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Abstract. Light-emitting devices play a vital role in people's lives, and their extremely wide application has won the attention and research of many scientists for a long time. Light emitting diode based on semiconductor energy band and electro-optical conversion is the mainstream light-emitting devices. Furthermore, control the light by nano optical technology such as plasmon effect and the quantum dot is also attractive. This article reviews the latest research progress of the above three light-emitting devices and their principles and characteristics. Finally, we briefly summarized the advantages and disadvantages of these devices, as well as the possible development directions and potential applications of the next generation light-emitting devices.

1. INTRODUCTION
Color is a comprehensive phenomenon involving light, objects and vision[1]. In the development of human material life and spiritual life, color always glows with magical charm. People continue to deepen their understanding and application of color through the changes of time[2]. For color research, pioneers at home and abroad have paid attention to it more than a thousand years ago[3,4,5]. The invention of pigments is undoubtedly a strong proof[6]. The ancient Egyptians used soil, rocks and other materials to invent the earliest synthetic pigments and applied them to murals. Traditional pigments have limited retention period, poor adjustment ability and low pixels[7], which cannot meet some modern applications. But after the 17th century scientist Newton really gave scientific reveal, color became an independent subject. At the same time, displays used to display colors such as Light Emitting Diode (LED), Liquid Crystal Display (LCD), play an indispensable role. Furthermore, light tunable devices such as Surface plasmon resonances (SPR) and quantum dots, etc. also play an important role. Since modern times, there have been endless researches on color displays. I. Akasaki, H. Amano and S. Nakamura invented the high efficiency blue LED in 2014. However, due to the weak luminous intensity, early LEDs were only used for indicators, displays or emergency lighting and other fields [8]. In 1973, Japan's SINBO used LCD for the first time to make digital displays for electronic calculators[9]. However, the problems of uneven brightness and low color reproduction are also worthy of improvement. In recent years, SPR and quantum dots are attractive in high-resolution color displays.

This manuscript overviewed previous research and development of LEDs, SPRs, quantum dots and other potential light-emitting devices. The progress in the research of light-emitting devices is mainly manifested in many aspects such as improved pixels, increased lifespan, and high luminous efficiency. We discussed the practical advantages and potentials of color display technology and their limitations. The article summarizes the development history of the above-mentioned devices, which could provide certain guidance and navigation for the possible development direction and potential applications of light-emitting devices in the future.
2. SPP
The next subsections provide instructions on how to insert figures, tables, and equations in your document. Since the plasmon nanostructures offer a way to the diffraction limit, people have spent a lot of energy on this research in recent years. It was not until the proposal of surface plasmon resonance that the method provided people with a more efficient and precise way to control color. Metal nanostructures have been proven to manipulate optical properties (such as light intensity, phase, polarization, etc.) through their surface plasmon resonance. Effective plasmonic nanostructures with small size are beneficial to the integration and miniaturization of display devices while recent studies have also demonstrated that color printing with plasma nanostructures can reach the diffraction limit. Compared with chemical pigments, metal nanostructures are stable and can withstand long-term ultraviolet radiation and high temperature.

The typical Kretschman[10] model is taken as an example (Fig.1). When a beam of polarized light enters the three structures of prism, gold film, and environmental medium at a certain angle, the angle of the incident polarized light is changed so that the incident light is totally reflected at the interface between the prism and the metal film, a part of the transmitted light will pass through and form an exponentially attenuated evanescent wave (Evanescent Wave) on the surface of the metal film. This evanescent wave will excite the tiny cells inside the gold film and then provide surface plasmons.

Hongrui Yuan and others studied the enhancement of quantum dots in the nanogap of the Au Nano-Sphere-Ag Nanowire coupling structure and the conduction characteristics of surface plasmons; Chen Jiawei and his team found that the surface plasmon of precious metal nanostructures can adjust the phase of the emitted light on the nanoscale by adjusting the shape, size and orientation of the nanostructures, so as to achieve abnormal reflection and transmission, focusing, holographic imaging, etc. Function, even has very important application prospects in the field of nonlinear beam control; Badshah Mohsin Ali et al. also pointed out that the electromagnetic field generated by the interaction of light and metal nanostructures can improve the sensitivity of fluorescence detection, and this enhanced perception ability It is important for many research fields. Many previous studies have confirmed the importance of metal nanostructures in SPP technology. We mainly study the application of different metal materials in plasma nanostructures and their respective advantages and summarize them.

![Fig.1 Kretschman model of SPR](image)

2.1. Silver
Silver is a common plasmonic nanostructured material. One of its typical applications in plasmonic nanostructures is to make dense silver nanorod arrays in order to explore the effect of its periodicity and diameter/periodity ratio on plasmon resonance. By controlling its geometry, we show that such nanorod arrays can tune plasmons to resonate and further reflect various colors. Therefore, it can be used as a reflective plasmon color filter. Silver can also be used as a raw material for silver gratings. Figure 2 shows a color-reducing filter with sub-wavelength periodicity and ultra-thin one-dimensional silver (Ag) grating. Since Ag is optically thinner, the ratio of transmittance at non-resonant
wavelengths and resonant wavelength is higher, which is efficient in the design of subtractive color filters. L. G. Daza[11] also has investigated Covering with silver nanoparticles, by Cadmium telluride (CdTe) thin films.

Fig.2 Schematic of the designed Ag grating.

2.2. Gold
In addition to metallic silver, gold is also widely used in plasma nanostructures. For example, a MIM nanostructure containing an array of gold nano disks can support interstitial surface plasmons (Fig.3). By adjusting the size, thickness, period of the disc and the thickness of the dielectric layer, the reflection can be flexibly adjusted. Kaushal Sandeep et al.[12] have examined the effects of dimension and distribution of gold nanorods. Wang Jun et al. also learned compared with gold nanorod structures, gold nano bipyramid have greater tunability of longitudinal surface plasmon resonance and stronger local field enhancements, which will be beneficial to gold nano bipyramid and gold nanorod application in optical sensing, surface-enhanced Raman scattering and infrared photothermal treatment. In short, gold nanoparticles are widely used in plasmon resonance structures. They generally have significant advantages such as high stability and strong resonance, but at the same time, the disadvantages of high cost are also obvious.

Fig.3 Schematic views of a cell of a MIM structure with Au nano disks.

2.3. Other Materials
In addition, the application of metallic materials in plasma nanostructures has other forms, such as combining gold and silver into a composite material or replacing it with aluminum. Among the coupled plasma nanostructures, nano disk suspended on top of a dielectric and a complementary metal hole as a back reflector is interesting. depositing gold-silver film on the hydrogen silsesquioxane
pillars, and resonance can be adjusted by the space between the pillars and the size of the disks, as shown in Figures 4a and 4b. To enrich the color gamut, the core materials can be replaced by aluminum. Aluminum is the preferred metal for plasma color printing because of its neutral tone, durability, and visible light range. The high reflectivity and low cost. However, aluminum also has the disadvantage of being easily oxidized, which will affect the excitation of SPR. Through different gaps and disc sizes, a single pixel is constructed by mixing discs of different sizes. What’s more, Yu Hua et al.[13] have found that the high plasma response of Aluminum allows multiple resonant frequency in visible range. Furthermore, deep-ultraviolet SPR sensor have also been obtained by changing the thickness of hybrid graphene layers and aluminum film [14].

In addition, there is also a metal-insulator-metal (MIM) structure in which resonance can also be used to split white light to different colors. In Figure 4e, the MIM grating is composed of aluminum-zinc selenide-aluminum resonators. The bottom aluminum grating can couple incident light to waveguide mode, the top grating converts the confined mode into propagated wave. The transmission of specific wavelengths was effectively enhanced by the photon-plasma-photon conversion. The period of this kind of MIM grating can achieve any color, such a small period also helps to obtain high-resolution color images and displays (Figure 4f).

3. QUANTUM DOT LUMINESCENCE

3.1. Quantum dot color development principle
The spectrometer is composed of a filter and a detector. The filter as the core part is a device for selecting colors and can play a role in color display. At present, interference optical devices such as the filters used in microscopic spectrometers still have limitations in terms of photon efficiency, resolution, and spectral range. How to solve these problems is still the direction of many scientists' efforts to study. Traditional filters separate different light bands before measuring the intensities, as shown in Figure 1. Another operating mechanism of filter is to use tunable absorption filters, and reconstruct the target spectrum based on measured intensity. A suitable broadband filter with proper system compatibility and light stability has not been easily available so far. The discovery of colloidal quantum dots (CQDs) provides a practical solution to the above problem by virtue of its continuously adjustable and size-dependent band gap.
The two-dimensional absorption filter array composed of colloidal quantum dots replaces traditional interference optics. Its advantage lies in the measurement of spectra based on the principle of wavelength multiplexing—a filter and a detector are used to simultaneously encode and detect multiple spectra Band. The test and analysis show that the performance of this two-dimensional absorption filter meets the required requirements, so the scheme is reasonable and feasible. Therefore, colloidal quantum dots are ideal broadband filter materials and they will play an important role in complexity, minimizing the size and cost of the spectrometer.

3.2. Application
The most widespread application of colloidal quantum dots is in the filter of quantum dot microscopic spectrometers, which have absorption characteristics covering the 300-nanometer spectral range. The adjustment of material and size in filter can realize precise control of wavelength, so as to realize different color changes. Another advantage the improved filter brings to the quantum dot spectrometer is that it can analyze the incident light with a wide angular distribution, which means that it has a greater concentration of light than traditional spectrometers. Simplifying the system by using CQD filters instead of dispersive optics can also significantly reduce the size of the equipment, and it is expected that quantum dot spectrometers of several orders of magnitude can be produced without compromising the spectral range or resolution.

Although quantum dots have incomparable advantages in color applications, they also have certain disadvantages. For example, due to the use of a large number of light-emitting quantum dots to ensure the increase in brightness, the power consumption of quantum dots is very large. Another serious shortcoming is that the price of electronic devices made of quantum dots is generally higher, which makes them lose a certain degree of initiative in the market. In general, the advantages of using quantum dot-related principles to make electronic devices are still very obvious, and its application range is very wide.
Figure 6 Al nano disks for plasmonic color pixels.

4. Conclusion

Light-emitting devices are immensely of great use in people's lives, and their extremely wide application has won the attention and research of many scientists for a long time. LEDs, metal strips, quantum dots, etc. are all mainstream and potential light-emitting devices. The light-emitting principle is the electro-optical conversion of the LED based on the semiconductor energy band, the metal strip is based on the plasmon effect, and the quantum dot includes a mixed mode of the two. This article reviews the latest research progress of the above three light-emitting devices and their light-emitting principles and structures. Finally, we briefly summarized the advantages and disadvantages of current devices, as well as possible future development directions and application potential.

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