Research Article

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# An Experimental Analysis on Spectrum Absorption Characteristics of High-Temperature Material Based on Nanostructure

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## Abstract
*High-temperature metal nanostructure endows various potential appli- cations in optical communication, aerospace and other fields. In this let- ter, periodical nanostructure with high-temperature metal is proposed to enhance spectrum absorption. The absorption characteristics and mech- anism were investigated and analyzed in the range of 360 ~ 760 nm wavelength based on the finite difference time domain (FDTD) method. The results indicate that particle shape, material, and period are the main factors affecting absorption. After optimization, the peak and aver- age absorption reach 68.6% and 61.32% respectively. The coupling between surface plasmon polaritons (SPPs) and local surface plasmon resonance (SPR) enhances the optical properties obviously. The results have certain reference value for the application of high-temperature metal nanostructure in special environments.*

## 1. Introduction
The research on the operating characteristics of light absorbers in visible and infrared bands have important value in opti- cal communication, atmospheric environment monitoring, thermal radi- ation, infrared detection, aerospace, biomedical imaging, military and other important fields [1, 2]. It has become a research hotspot to use surface plasma to control optical properties. Surface plasma is a kind of electromagnetic surface wave, where the field strength is the largest. When the light shines on the metal surface, the interaction between free electrons and photons will produce collective oscillation and generate surface plasmon polaritons(SPPs) locally, which will bind the light field near the metal surface, thus reducing the light reflection and enhancing the absorption of the surface [3].

In this letter, we have simulated the relationship between the absorp- tion of high-temperature metals and the shape, material, and period of nanostructure in the range of wavelength 360 760 nm based on the Finite Difference Time Domain (FDTD) method. The impacts of dif- ferent parameters on the absorption characteristics and the absorption mechanism behind the optical phenomena can be discussed accordingly.

## 2. Structure model
The metal nano-array with a period length of $P$ extending along the x-axis and y-axis is shown in Fig 1. It's a two-layer structure, with the metal substrate layer below and the metal nanoparti- cle array above. The incident light shines to the structure surface from the air interface vertically. Periodic boundary conditions and perfectly matched layer technology (PML) are used in the calculation. The absorp- tion $A = 1\ R\ T$, where $R$ is the reflectivity and $T$ is the transmittivity [4].

Five kinds of nanoparticle arrays with different shapes are considered and named Circle nanoparticle array, Pyramid nanoparticle array, Rect- angle nanoparticle array, Ring nanoparticle array, and Sphere nanoparti- cle array, respectively. They have the same height of $h$ = 200 nm and the bottom or central cross section (spherical particles) has the same area of 200 nm x 200 nm approximately.

## 3. Simulation results
The absorption of periodic arrays with different par- ticle shapes while $P$ = 1800 nm is shown in Fig 2. The materials of the substrate and nanoparticles are high-temperature metal Titanium (Ti). The five nanoparticle arrays aforementioned have different absorp- tion characteristics, in the range of wavelength 400 ~ 625 nm.

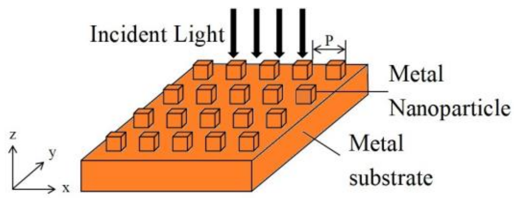



**Figure 1:** The metal periodic nanostructure under consideration

The absorption of Pyramid nano-array is the highest, with the absorption peak exceeding 57%, followed by Circle and Rectangle nano-array. The absorption of Sphere and Ring nano-array is lower. The absorption of Sphere and Pyramid nano-array is higher in the range of wavelength 625 760 nm, while Ring nano-array is slightly lower than that of Cir- cle and Rectangle nano-array, with the lowest absorption of 42%.

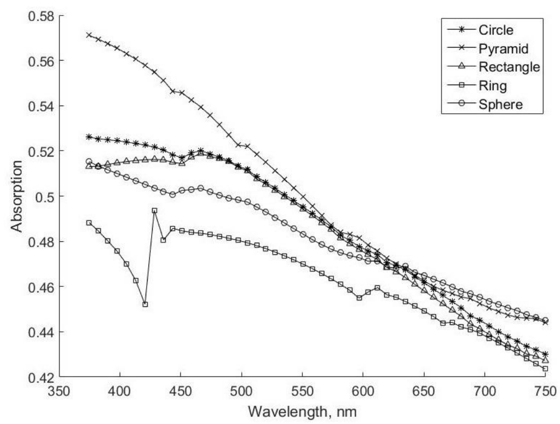



**Figure 2:** Absorption of periodic arrays with different particle shapes while *P* = 1800 nm.

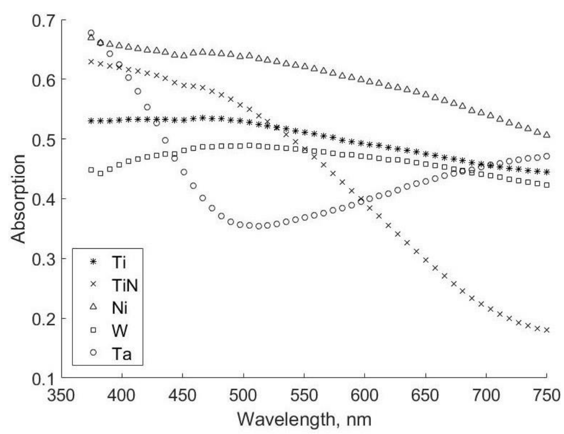
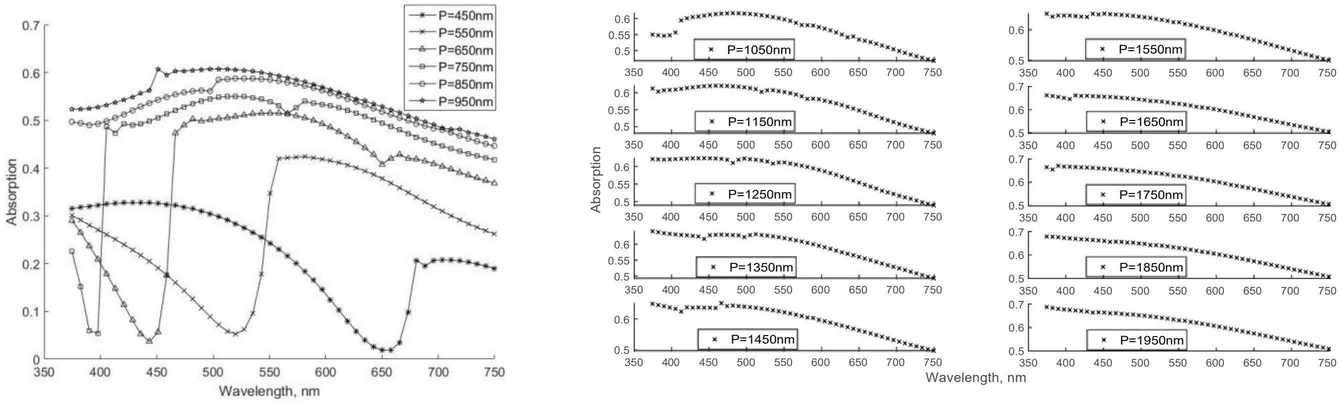


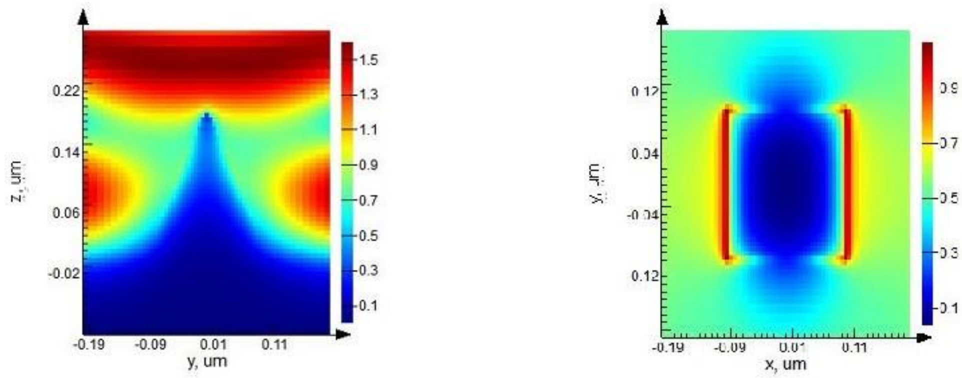

**Figure 3:** Absorption of Pyramid nano-arrays of five high-temperature metals.

Figure 3 shows the absorption of Pyramid nano-arrays of five high- temperature metals. The absorption of Nickel (Ni) nano-array is much better than Ti, Titanium Nitride (TiN), Tungsten (W) and Tantalum (Ta) nano-array. Ti nano-array is slightly higher than W nano-array, and they gradually approaches each other with the increase of wavelength. The absorption of Ta nano-array decreases first and then increases with the increase of wavelength, and an absorption valley of 35% is generated at 512 nm. Although the absorption of TiN nano-array is obviously bet- ter than Ti and W nano-array with the highest absorption of 62.9% in the wavelength range below 520 nm, but when the wavelength is above 520 nm, the absorption of TiN is much lower than Ti and W. The aver- age absorption of Ni, Ti, W, Ta and TiN nano-array is 60.33%, 50.02%, 46.45%, 44.41% and 43.35% respectively. The average absorption of Ni nano-array is obviously higher than that of the other four materials, and the absorption difference is above 10.31%.




**(a)** **(b)**

**Figure 4:** Absorption of Pyramid Ni nano-array with different periods. a Absorption in the range of wavelength 450 ~ 950 nm. b Absorption in the range of wavelength 1050 ~ 1950 nm




**(a)** **(b)**

**Figure 5:** *E field distribution of Pyramid Ni nano-array at the wavelength of 400nm with P=750nm. (a) Ex of the pyramid particle central section. (b) Ez of the pyramid particle bottom section*

Figure 4 shows the absorption of Pyramid Ni nano-array with dif- fer- ent periods. Fig 4(a) and Figure 4(b) correspond to the absorption in the range of wavelength 450 950 nm, 1050 1950 nm respectively. Fig 4(a) shows that the absorption enhances obviously with the increase of *P*. When *P* is less than 850 nm, the absorption width becomes wider, the absorption peak gradually increases, and the the absorption peak appears blue-shift with the increase of *P*. When *P* = 850 nm or 950 nm, there is no obvious absorption peak. With the increase of wave- length, the absorption efficiencies gradually approach each other. Fig 4(b) shows that the absorption gradually enhances with the increase of *P*. The absorption peak reaches 68.6% and the average absorption reaches 61.32% when *P* = 1950 nm.

The E field distribution of Pyramid Ni nano-array at the wavelength of 400 nm with *P* = 750 nm is shown in Fig 5. Fig 5(a) shows the distribution of E field in the x-axis direction (Ex) of the pyramid particle central section, whereas Fig 5(b) shows the distribution of E field in the z-axis direction (Ez) of the pyramid particle bottom section. In Fig 5(a), the E field is concentrated near the waist and around the top of the Pyramid, and it is coupled symmetrically. The SPPs and local surface plasmon resonance(SPR) are generated on the structure surface. Fig 5(b) shows that the E field is concentrated at the edge of the bottom section of the Pyramid particle, and the coupling of the local SPR is enhanced under the action of the adjacent SPPs. The increase in absorption width and peak value, and the blue-shift of absorption peak are caused by the interaction of SPPs and local SPR [5].

## 4. Conclusion

The particle shape, material and period are the main fac- tors affecting absorption characteristic of high-temperature metal nanos- tructure. Metals with energy absorption affect the optical properties by different transition levels. The interaction between SPPs and local SPR makes the E field distribution on the metal surface uneven and the strength is strongest at the edge, which induces the optical field being limited near the edge and enhancing its optical characteristics.

In this research, the absorption characteristics of high-temperature metal nanostructure have been better enhanced by changing parameters of the shape, structure, period.

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