Article ID: 1000-5773(2005)02-0184-05

The Influence of Temperature on Photoemission from Silver Nano-Particles Embedded BaO Thin Film*

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Abstract: The Dependence of the spectral distribution of photoemission from silver nano-particles embedded in BaO semiconductor thin film on temperature are predicted and investigated theoretically. At high temperature the photoemission response curves to wavelengths from 0.2 to 0.8 μm are given. It is showed that the higher temperature, the higher photoemission from silver nano-particles embedded in BaO. An explanation is also presented. It is also pointed out that the critical diameters of silver nano-particles between discrete electron eigenstates (quantum sizes region) and quasicontunuous energy bands for energy band of silver ultra-fine particles in the BaO are less than 3.8 nm

Key words: photoemission; thin film; semiconductors

CLC number: O521.2 **Document code**: A

1 Introduction

Ag-BaO is a new kind of photoemissive thin films, which is different from the traditional photoemissvie materials. It consists of Ba oxide thin film embedded with Ag metallic ultra-fine particles[1~3]. Because the traditional photoemissive containing alkali elements (such as Ag-O-Cs, Cs_3Sb, $[Cs]Na_2KSb$)[4], this kind of thin films can not be exposed to the atmosphere and can not work at high temperature. If they have been exposed to the atmosphere, those films will be worthless. Those drawbacks limit an extent of its applications. However, AgBaO don't contain alkali elements, and can be exposed or stored in the atmosphere and can be used again in a vacuum system without any activation process for the laser-pulse detection. Other speciality is that its response rate is faster than the laser pulse duration of several piconseconds. Its potential applications in ultra-fast optical communication and detecting ultra-short laser pulses prompt experimental and theoretical studies of it.

This work is an extended our early research[5]. The main purpose of this paper is to report the theoretical results on dependence of the photoemission from sliver ultra-fine particles embedded in BaO thin film on temperature.

2 The Formulae of the Spectral Distribution of the Photoemission for Ag-BaO Thin Film

In our early research[5], a formula following is used to calculate photoemission from the Ag-BaO thin film

* **Received date**: 2004-07-03; **Revised date**: 2004-09-22
Foundation item: Project supported by the Nature Science Foundation of Yunnan Province under grant 2004A00229M.
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$$\frac{J(h\nu)}{I_0}=\frac{h\nu}{[(h\nu_r)^2-(h\nu)^2]^2+(\bar{h}\Delta\omega_{1/2})^2(h\nu)^2}\cdot \int_{E_t-E_V}^{\infty}\frac{[E+(E_\nu-h\nu)]^{1/2}}{[E+(E_\nu-E_-)]^{1/2}}\cdot\frac{E}{\exp[(E-E_m)/kT]+1}\mathrm{d}E \quad (1)$$

Where $J(h\nu)$ is the photon-emission current density, illuminated by incident light of intensity I_0 and photon energy $h\nu$. The term before the integral is due to resonance absorption of radiation by silver nano-particles suspended in BaO. The integral term is photon-electron transport. The $\bar{h}\Delta\omega_{1/2}$ is the full width at half maximum of optical absorption.

In the Ag-BaO thin film, metal silver nano-particles are brought into contact with BaO semiconductor thin film, as showed in Fig. 1. Upon the close contact of metal silver and BaO semiconductor, the electrons in metal silver flow into the BaO semiconductor. The Fermi levels in the two materials must be coincident at thermal equilibrium, which form metal Ag-BaO semiconductor barrier. The results for metal silver nano-particles and BaO semiconductor are similar to the p-n junction. In Fig. 2 (a), (b), (c), E_V is the vacuum level, E_F is Fermi level, E_{FM} is Fermi level of metal silver, E_{FS} is Fermi level of BaO semiconductor, E_- and E_+ are conduction band bottom level and top valence band level for BaO semiconductor matrix respectively, E_t is an equivalent barrier around silver nano-particles. All values of the energy levels presented above are with reference to the conduction band bottom of silver nano-particles. The photoelectrons coming from silver nano-particles will probably enter the BaO semiconductor layer and escape from the surface if their energy is higher than E_t.

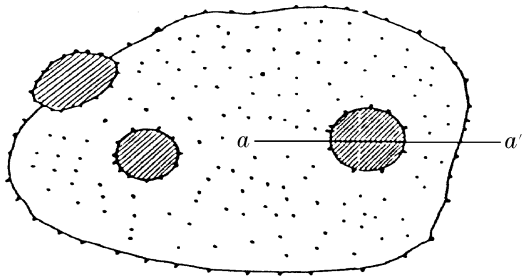


Fig. 1　BaO semiconductor thin film embedded with silver nano-particles (Shades represent silver nano-particles, dots represent electrons)

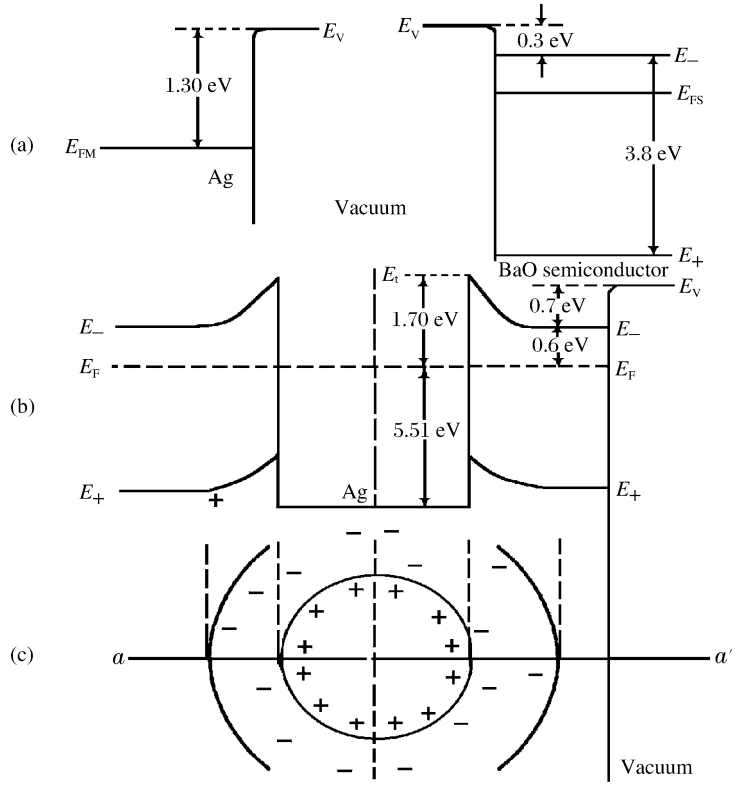


Fig. 2　(a) Energy level diagram of silver and BaO semiconductor before the contact; (b) Energy band position diagram in the neighbourhood of Ag-BaO surface; (c) Charge distribution.

In equation (1), these physical parameters were follow[2]: $(E_t-E_F)=1.7$ eV, $(E_V-E_F)=1.3$ eV, here $E_F=5.51$ eV. The electron affinity is $E_A=E_V-E_-=0.7$ eV, so we obtain $(E_t-E_V)=0.4$ eV, $(E_--E_F)=0.6$ eV, $E_V=6.81$ eV. We let $h\nu=2.43$ eV ($\lambda_P=519$ nm), $E_m=(h\nu-1.3)$ eV.

v_F is the velocity of electrons

with the Fermi level, L is the mean free path. There is the following relation between L and v_F

$$L = v_F/(\Delta\omega_{1/2}) \tag{2}$$

For silver, $v_F = 1400$ km/s. From equation (2), $L = 1.54$ nm is gotten, which is much smaller than mean free path (57 nm for bulk silver under 273 K). The silver nano-particles surface is regarded as a scatter of conduction electrons. Assuming this scattering process to be diffusion and silver nano-particles to be uniform sizes and spherical shapes, the appropriate mean free path L_{spehere} of electrons, disregarding its coupling to the Fermi liquid, can easily be calculated for spherical particles

$$L_{\text{sphere}} = \int L(\theta)\,\mathrm{d}w \Big/ \int \mathrm{d}w \tag{3}$$

$L(\theta)$ is the free path of an electron leaving an infinitesimal surface element df at an angle θ to its normal, after a scattering event. Provided that all scattering mechanisms of the conduction electrons in a spherical particles are independent of one another, if the number of scattering events per unit time, $\mathrm{d}w$ is

$$\mathrm{d}w = C\tan t \cdot df\,\mathrm{d}\Phi \tag{4}$$

Where $\mathrm{d}\Phi$ is the solid angle, we get

$$L_{\text{sphere}} = R \tag{5}$$

This result means that the dimension of silver nano-particles limits the free electrons. Therefore, L_{sphere}, the equivalent diameter of silver nano-particle will be L.

3 Results and Discussion

Here we let $\hbar\Delta\omega_{1/2} = 1.848, 1.200, 0.615, 0.182, 0.092$ eV, the equivalent diameter of silver nano-particle will be 1.00, 1.54, 3.00, 4.00, 10.00, 20.00 nm. Under different temperatures ($\hbar\Delta\omega_{1/2} = 0.6$ eV, $T = 300, 360, 420, 480$ K), using equation (1), theoretical photoemission spectra distribution from silver Ag embedded in BaO thin film are calculated as shown in Fig. 3 (a)～Fig. 3 (f). Because of BaO semiconductor thin film with a large forbidden energy bandwidth, the electron excitation by the incident in it can be negligible and is considered to be transparent to visible light. Consequently, the light absorption of the thin film arises mainly from that of Ag nano-particles. Thus there are only two terms, which consists of the resonance absorption of radiation by silver nano-particles suspended in BaO and the photon-electron transport in formula (1).

There are two coupling thermal systems in silver nano-particles. One is the crystal lattice and another one is the electrons system. When the temperature of thin film increases, the number of electrons near the Fermi level also increases. Actually temperature elevated the electron temperature, resulting in a change in the electron state densities of the electrons with the energy lower than the Fermi level decrease and those of the electrons with the energy higher than the Fermi level increase, which gives rise to the change in transition possibility of the electrons. Upon the incidence of light, energy of photons are first absorbed by free electrons near the Fermi level, which cause photoemission to increase as showed in Fig. 3. When the size of nano-particles silver become large, the theoretical spectral distribution of photoemission shift up for clarity, and the peaks of the theoretical spectral distribution become narrow sharply and move to long wavelength.

It is known that there is a critical diameter (d_c) between discrete electron eigenstates (quantum sizes region) and quasicontunuous energy bands for the energy band of silver ultra-fine particles. The critical diameter is determined by many factors, such as temperature, the method of preparation of silver ultra-fine particles, the form and the structure of silver ultra-fine particles, the impurities of matrix BaO, and the nature of the embedded matrix. It should be possible experimentally to decide whether a

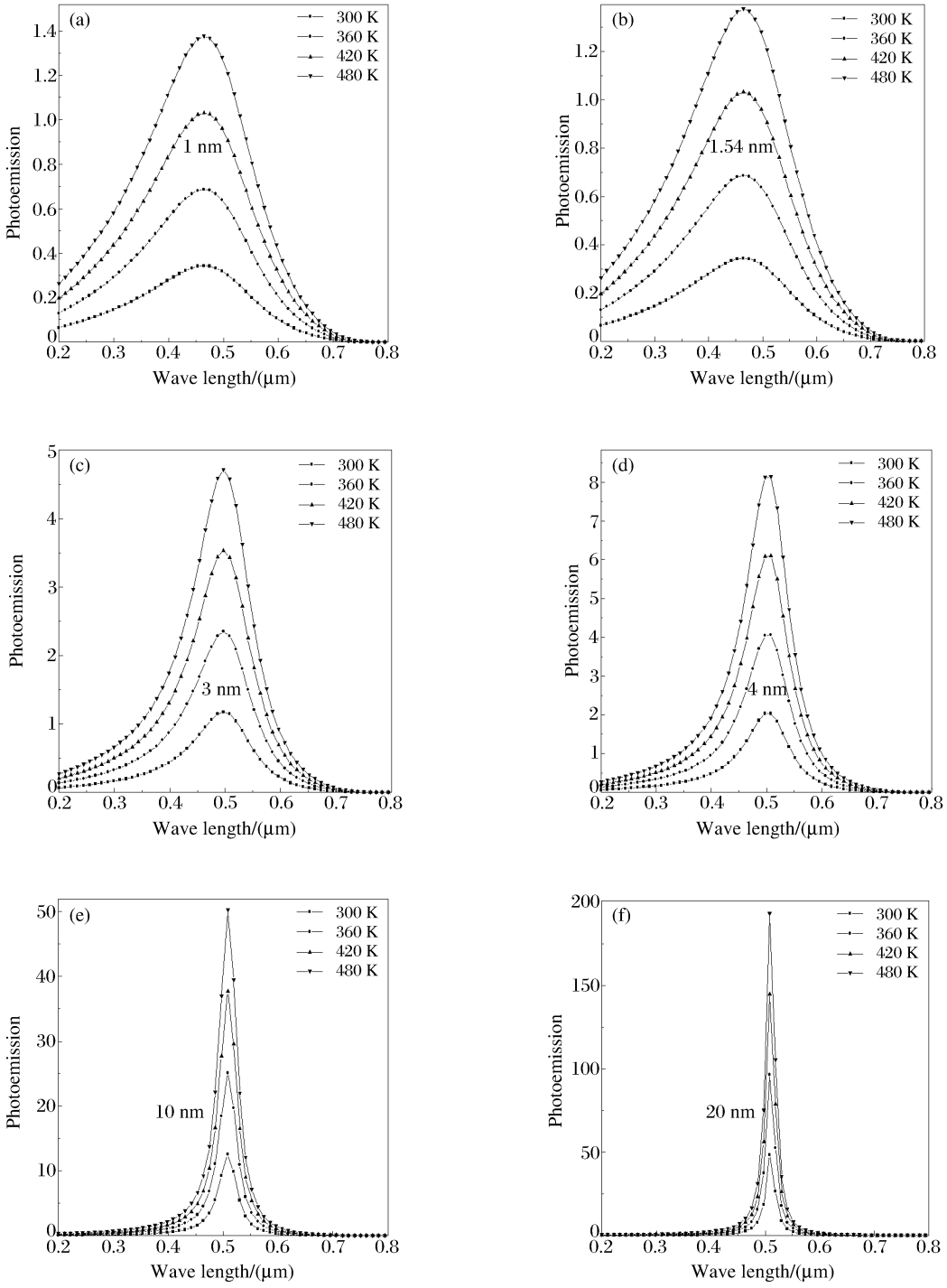


Fig. 3　The influence of temperature on the photoemission from silver nano-particles embedded in BaO thin film

quaicontinuous bands model or a discrete eigenstates model is appropriate for the Ag-BaO thin film, which has been done by investigating spectral distribution of the photoemission for the Ag-BaO. After comparing the experimental curves of the long wavelength response, this quacontinuous bands model is valid for Ag-BaO[2,3]. So the critical diameters of silver ultra-fine particle in the BaO are less than 3.8 nm. In summary ambience temperature cause the number of electrons increase and photoemission shift up.

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温度对来自镶嵌在 BaO 薄膜中的纳米银粒子的光电发射影响

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摘要: 研究了温度对来自镶嵌在 BaO 薄膜中的纳米银粒子的光电发射的影响。在不同温度下计算和讨论了其光电发射谱(入射波长在 0.2～0.8 μm)。光电发射谱中温度越高, 光电发射峰越大。同时发现镶嵌在 BaO 薄膜中银纳米的临界尺寸小于 3.8 nm。

关键词: 光电发射; 薄膜; 半导体

中图分类号: O521.2 **文献标识码:** A