Research on the Application of Physical Properties of Optoelectronic Films in Passive Devices for Optical Communications

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Abstract. Thin films play an important role in modern science and technology. With the development of optical fibre communication technology and laser technology, thin films are used more and more widely in this field. The application of optical film in optical communication and laser technology is introduced systematically. The application of optical films in optical communications basically covers a variety of conventional optical films. Based on this research background, the paper mainly analyses the optical and physical properties of zinc oxide nano-films and discusses its application in optical communication.

Keywords. Optical electronic film, optical communication, physical properties, zinc oxide nano film.

1. Introduction
Optical film is an important part of modern optical devices. It uses the interference effect of light to change the polarization, phase and energy of the transmitted or reflected light by coating one layer and multiple layers on the surface of various optical materials. The film can be coated in crystals, plastics, optical glass and other materials, the most commonly used substrate is optical glass. The thickness of the film can be from a few nm to hundreds of μm, and the number of layers can be from one to several hundred. Generally speaking, these materials Both the structure and the structure are obtained through film growth in a non-equilibrium state [1]. Therefore, thin film science has gradually become a science that studies thin film preparation technology, growth mechanism, control methods and physical property analysis. After nearly 20 years of development, thin film science has included extremely rich content. The importance of thin films in modern science and technology is increasing rapidly. It is no exaggeration to say that all kinds of science and technology are inseparable from thin films, and there is no other technology that can replace thin films. Without the development of thin films, it is difficult to imagine that many complex and high-performance optical, optoelectronic and electronic systems can be successful.

Based on this research background, the thesis first analyses the application of optical electronic thin films in the communications industry, and studies the properties of magneto-thermoelectric transport, which will help to better understand the electronic energy spectrum structure, etc., and then design the
excellent performance of the ZnO-based carrier. Lay the foundation for the development of optoelectronic devices, thermoelectric material devices, and sensor elements.

2. Passive components

2.1. Optical fibre connector
Fiber optic systems are also like electronic circuit systems, requiring many passive components to realize the connection, splitting, combining, switching, isolating, and controlling or changing the propagation characteristics of optical signals. Optical film is very important in some occasions. For example, in the lens expander type connector, the surface of the lens needs to be coated with an anti-reflection film to eliminate the influence of Fresnel reflection [2]. The lens expander or connector uses one lens to collimate the reflected light beam, and then uses another lens to focus the beam on the receiving fibre. The advantage of this connector is that it reduces the sensitivity of the lateral offset during the fibre connection process, because the width of the beam between the lenses at this time is much larger than the width of the beam between the fibers of the butt-type connector; in addition, due to the area of the lens end face It is much larger than the area of the fibre core, which greatly reduces the pollution of the light-passing surface. It is suitable for the connection of array optical fibers.

2.2. Fiber Directional Coupler
It is an optical passive device used to distribute and transmit optical signal power. The optical signal power is input from one port of the coupler, and then distributed to several designated ports according to a certain ratio. This is called "splitting". On the contrary, the optical signal power source couplers input by several ports are coupled into the same port and output, which is called "combination". The self-focusing optical directional coupler composed of quarter-pitch gradient index cylindrical lens (GRIN) and the principle of partial reflection of light is shown in Figure 1.

![Figure 1. Self-focusing coupler](image)

The partially reflective dielectric film is plated on the bonding surface of the two lenses. When the light enters the surface of the first GRIN lens from the input fibre, part of the light is output by 3 outlets according to a certain proportion (as required, the coating system). The light transmission is output by 4 outlets. Similarly, the input power from the 2-port will be proportionally distributed to the 3-port and 4-port output. However, the optical signals are isolated from each other between the 1 port and the 2 port and between the 3 port and the 4 port. In addition, due to the reversibility of optical transmission, this coupler can also be used in reverse. That is, the optical signal is input by ports 3 and 4, and output by ports 1, and its various characteristics remain unchanged [3]. The directional coupler composed of this kind of micro-optical components has compact and simple structure, low insertion loss (<1dB) and is insensitive to mode power distribution, so it has many applications. Part of the dielectric reflective film can also be plated on the inclined surface of the right-angle prism.
3. Properties of Zinc Oxide Nano-Film and Optical Communication Application

3.1. Magnetic Seebeck effect
The magnetic Seebeck effect is essentially a Hall effect. The Boltzmann equation including light-excited carriers is

$$\frac{df}{dt} + \mathbf{v} \cdot \nabla f + \mathbf{k} \cdot \nabla f - \left( \frac{\partial f}{\partial t} \right)_{\text{coll}} + G - R = 0 \quad (1)$$

Here, $f = f(k,r,t)$ represents the distribution function of carriers in the phase space, and $G$ and $R$ are the generation rate and recombination rate of light-excited carriers, respectively.

$$\mathbf{v} = \frac{\partial f}{\partial E} \frac{E}{h} = \frac{Ze}{h} \left[ \nabla_v (-\varepsilon_b / Ze) + \mathbf{v} \times \mathbf{B} \right] \quad (2)$$

$\varepsilon_b$ is the edge energy, and $Z = -1$ is when considering electrons. Under no light excitation (light irradiation), steady state and relaxation time approximation (RTA), the equation becomes

$$\frac{df}{dt} + \mathbf{v} \cdot \nabla f + \mathbf{k} \cdot \nabla f = - \left( \frac{\partial f}{\partial t} \right)_{\text{coll}} = - \frac{f - f_0}{\tau} \quad (3)$$

$f_0$ represents the equilibrium distribution function of the carrier in the phase space, and $f$ is the unbalanced distribution function (when the external field is not too strong, it can sometimes be regarded as the equilibrium distribution function). $\tau$ is the relaxation time. Solving Boltzmann equation methods: function transformation method; Legendre function expansion method; iterative method (stepwise approximation method); variational method; Monte Carlo method; inverse operator action method, etc.

We use the function transformation method to solve the equation below. make

$$f = f_0 - \mathbf{v} \cdot \Psi \left( \frac{\partial f_0}{\partial E} \right) \quad (4)$$

We take (4) into equation (3) and after more complicated mathematical operations, $\Psi$ is

$$\Psi = \tau \left[ \mathbf{p} - \alpha \mathbf{v} \times \mathbf{B} + \alpha \mathbf{v} \times \left( \mathbf{p} \cdot \mathbf{H} \right) \right] \quad (5)$$

Where $\omega = \frac{|e| B}{m^*}$ is the cyclotron frequency of electrons in a magnetic field.

$$\mathbf{p} = e \mathbf{v} + \left( \frac{\varepsilon_b}{e} / e \right) - TV_v, \left( u_b / e \right) - \left( \varepsilon / e \right) V_v, T \quad (6)$$

$\mu_b$ is the chemical potential. Combining equations (4), (5), (6), the distribution function $f$ can be obtained.

3.2. Calculation of transport coefficient
$g_{2D}(\varepsilon) = \frac{4\pi m^* S}{aSh^2} = \frac{4\pi m^*}{ah^2}$ is the density of states per unit volume of the two-dimensional film. $a$ is the film thickness. Define transport points:

$$K_j = \int_0^\infty \frac{\tau \varepsilon^j}{1 + \omega^2 \tau^2} \frac{\partial f_0}{\partial \varepsilon} d\varepsilon = \int_0^\infty \frac{\tau \varepsilon^j}{1 + \omega^2 \tau^2} \frac{\partial f_0}{\partial \varepsilon} d\varepsilon \quad (7)$$

$$H_j = \int_0^\infty \frac{\alpha \tau \varepsilon^j}{1 + \omega^2 \tau^2} \frac{\partial f_0}{\partial \varepsilon} d\varepsilon = \int_0^\infty \frac{\alpha \tau \varepsilon^j}{1 + \omega^2 \tau^2} \frac{\partial f_0}{\partial \varepsilon} d\varepsilon \quad (8)$$

The transport coefficient of the two-dimensional film can be obtained. The Fermi distribution function is

$$f_0 = \frac{1}{\exp \left( \frac{\varepsilon - \xi}{kT} \right) + 1}$$

The magnetic Seebeck coefficient is

$$\alpha(B) = -\frac{I}{eT} \left[ \frac{K_j K_\parallel + H_j H_\parallel}{K_j^2 + H_j^2} - \xi^* \right] \quad (9)$$
For the two-dimensional electron gas, when the Zeeman effect energy of the band edge energy and the electron spin with the external magnetic field is not considered, the dispersion relation is:

$$\varepsilon(k_x, k_y) = \frac{\hbar^2 k_x^2}{2m_e} + \frac{\hbar^2 k_y^2}{2m_e} - \frac{\pi^2 \hbar^2}{2m_e a^2},$$

if it is to be considered, it should be:

$$\varepsilon(k_x, k_y, B) = \frac{\hbar^2 k_x^2}{2m_e} + \frac{\hbar^2 k_y^2}{2m_e} - \frac{\pi^2 \hbar^2}{2m_e a^2} + \left(n + \frac{d}{2}\right) \hbar \omega_c + \frac{1}{2} g \mu_B \sigma B$$ (10)

We adopt a spherical iso-energy surface, a parabolic single-band, planar isotropic model, and the chemical potential of a two-dimensional semiconductor film can also be obtained by solving the quartic equation about it. We can use the transport integral to obtain other transport coefficients, such as the Nernst coefficient $N(B)$ and so on.

### 3.3. Calculation of relaxation time

The statistical average of the relaxation time to the distribution function is the average relaxation time, which determines the size of the mobility $\mu = \frac{-k}{m^*} \langle \tau \rangle$, and determines the transport properties of the material. It is second only to the most important quantity in semiconductor materials-the band gap, another very important physical quantity. The stress-induced field scattering may be related to film growth (such as substrate or substrate, matrix, growth temperature, annealing temperature, preparation process conditions, etc.). For polycrystalline TCO films, mainly ionic impurities, neutral impurities, acoustic phonons and grain boundaries scattering [4]. However, the concentration of neutral impurities and its scattering cross-section are smaller than that of ion impurities, so this kind of scattering is not considered. According to the Matthiessen rule, the relaxation time of mixed scattering including ion impurity scattering and acoustic phonon scattering is:

$$\frac{1}{\tau} = \frac{1}{\tau_{ii}} + \frac{1}{\tau_{ac}}$$ (11)

Among them, the modified ionized impurity scattering relaxation time based on the Brooks-Herring formula is

$$\tau_{ii}(\varepsilon, T) = \frac{16 \sqrt{2} \pi (\varepsilon, e_0)^2 e^{3/2}}{N_i Z^2 e^2 F_i(\varepsilon, T)}$$ (12)

Where $F_i = \ln \left[1 + z(\varepsilon, T) - \frac{z(\varepsilon, T)}{1 + z(\varepsilon, T)}\right], z(\varepsilon, T) = \frac{8 \varepsilon_0 \varepsilon_r m^* kT e^2}{\hbar^2 e n}$.

The above formula is $N_i$ ion impurity concentration, $n$ is electron concentration, and $\varepsilon_r$ is dielectric constant. Acoustic phonon scattering relaxation time

$$\tau_{ac}(\varepsilon, T) = \frac{\pi \hbar^2 \rho c_l^2 e^{-1/2}}{\sqrt{2} E^{3/2}_{ac} (m^* T)^{3/2}}$$ (13)

Where $c_l$ is the longitudinal sound velocity, $E_{ac}$ is the band edge deformation potential, and $\rho$ is the mass density.

### 4. Application of optical thin film passive devices for optical communication

#### 4.1. Optical films for optical communication

In the process of information technology development, it has promoted the development of optoelectronic technology in various aspects, such as optical fibre manufacturing technology, semiconductor lasers, optical fibre amplifiers, and optical passive devices. Thin-film optics technology plays an important role in current optical communications, improving device functions and improving the coupling efficiency of optical connections. Functional thin-film devices, such as interference filter
type WDM (wavelength division multiplexing) devices, are used in some systems. Play a key role. Some scholars have used liquid phase epitaxy to prepare YIG magnetic garnet films, and studied the influence of material formulation and annealing on the light absorption, Faraday rotation angle and induced anisotropy of the film [5]. The use of double-layer film structure waveguides can effectively reduce the linear birefringence of the film realizes single-mode transmission. With the development of optical communication technology, the current optical film is jumping out of the traditional category, broadening the prospects for the development of optical film technology. Optical thin film technology has also penetrated into many passive devices in optical communications. It can be foreseen that due to its unique advantages, optical thin film devices will occupy a more important position in optical communications.

4.2. Wavelength Division Multiplexer/Demultiplexer

Optical wavelength division multiplexer (WDM) is a wavelength selective coupler. It is a passive device used to synthesize optical signals of different wavelengths or separate optical signals of different wavelengths. The former is also called a "multiplexer"; the latter is a "multiplexer". "Demultiplexer", in theory, the frequency of the optical carrier is very high, and the bandwidth of the optical communication system can exceed 1THz, but in fact the capacity of the optical fibre is affected by the dispersion of the material and the dispersion of the waveguide, as well as the rate of other electronic devices, so the transmitted bits the rate is limited to 10Gb/S, or lower. This limitation is for the information carried by any wavelength. Therefore, by increasing the number of carrier wavelengths, the capacity of the optical fibre can be increased proportionally. Obviously, to increase the speed of optical communication, the very important way to increase the capacity of optical communication is to improve the technology of wavelength division multiplexing. The optical signals of different wavelengths (channels) are simultaneously transmitted in a fibre, so that the capacity of the optical communication system is increased several times, more than tens of times. The important performance indicators of the wavelength division multiplexer are: insertion loss Li, which refers to the power loss introduced when a signal of a specific wavelength passes through the corresponding channel of the WDM device [6]. It is usually hoped that Li is as small as possible; crosstalk (isolation) Lc, refers to the wavelength isolation or channel isolation; the channel bandwidth \( \Delta v_{ch} \) requires that the number of multiplexed channels N in the available optical fibre bandwidth is the larger the better, and the narrower the channel bandwidth the better. According to (OFC2000) reports, Tycoys has achieved 180 channels, a rate of 10Gb/s, and a transmission of 7000km. Japan's NTT (OFC2001) has developed AWG filters with 400 wavelengths and 25 GHz intervals. Due to the development of WDM technology, the optical fibre communication capacity increased from 45Mb/s in 1976 to 640Gb/s in 2000, an increase of 256 times.

Figure 2 shows the structure of a four-wavelength interference filter type wavelength division multiplexer, which is composed of a self-focusing lens and a light splitting element, as shown in Figure 2. An interference filter is sandwiched between every two 1/4 pitch lenses to separate optical signals between one wavelength. In this design, the first and third blocks are long-wave pass and short-wave pass cut-off filters, respectively [7]. The optical film, the second is a bandpass filter, the insertion loss of each channel is 0.5dB, 1.0dB, 1.1dB, 0.7dB, and the crosstalk loss between channels is greater than 25dB. Figure 3 shows another type of interference filter type actual 6-channel wavelength division multiplexer. The \( \lambda_1, \lambda_2, \lambda_3, \lambda_4, \lambda_5, \lambda_6 \) filters are vapor-deposited using wedge-shaped glass blocks to form a multi-reflective demultiplexer structure. When the optical signals of \( \lambda_1-\lambda_6 \) are input from the same optical fibre, the \( \lambda_1 \) light passes through the filter first Output, \( \lambda_2-\lambda_6 \) is reflected, and then \( \lambda_2 \) is output through the filter, and so on, to complete the purpose of multi-wavelength demultiplexing, by the reversibility of light, such as changing the transmission direction, input \( \lambda_1-\lambda_6 \) optical signals from 1-6 ports respectively, the synthesized signal is output from the original input port. In the structure, the glass plate plays the role of connecting, and the GRIN cylindrical lens plays the role of parallel light path.
5. Conclusion
Thin films play an important role in modern science and technology. With the development of optical fibre communication technology and laser technology, thin films are used more and more widely in this field. Traditional optical film has been widely used in people's daily life. Because of its excellent properties, it has brought convenience to people's lives. The new optical film has received extensive attention from people, and its research and development are also endless. It will have broad development prospects in all aspects, allowing it to play a more important role in all aspects of our lives.

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