The study of communication fibre amplifier based on doped nano-scale semiconductor materials

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Abstract

This paper firstly describes the development of communication fibre with InP-doped nano-scale semiconductor materials in detail, and then discusses its important dispersion characteristics, starting from the definition of fibre materials dispersion to explore the affected factors of dispersion, different dispersions on fibre as well as the dispersion features of single mode fibre. From the perspectives of experimental and theoretical calculations, it analyses the dispersion characteristics of drawing and doped nano-scale fibre. Thus, it will have much broader prospects for sano-scale semiconductor materials as doping fibre amplifier in communication.

Keywords: nano materials, communication optical fibre, fibre amplifier

1 Introduction

Composite material is now becoming application program which is accepted in much major structure, especially in space and aerospace, marine, civil engineering and automotive industry. In modern optical network, signal remote transmission relies on optical fibre transmission, and current backbone network in communication network also mainly depends on fibre-optic transmission. Fibber optic transmission system as long distance, high-speed and high-capacity backbone network, continues to be enlarged in transmission after the light signal attenuation is unavoidable [1]. The emergence of optical fibre amplifier has better settled down the enlargement of relaying, avoiding over-input of light-electricity-light transformation in time and cost, which provides transmission of high speed and long distance. Current existing amplifier with light mainly can be divided into three categories, including semiconductor laser amplifier, non-linear optical amplifier and doped optical amplifier [2]. Semiconductor laser amplifier is used for semiconductor laser unit working below the threshold, input from one end by amplified optical signal and enlarged in active terminal, output from another end. Non-linear optical fibre amplifiers mainly refer to fibre Raman amplifier using simulated Raman scattering effects of silica fibre in hard light with reasonable wavelength, to amplify the light signal. Doped fibre amplifier refers to silica fibre dope with rare-earth elements to form a multilevel system, under the continuous pumping of pump light realizing population inversion, and then use signal light to guide induction, the particles simulated for radiation transition, thus amplified the signal light.

Scale-up experiment of rare earth doped fibre firstly was held in 1964. With the development of GaAs semiconductor diode laser amplifier, the first diode pumping fibre laser realized the application in optical communication system in 1974. The reduction of optical fibre transmission loss and application development of InGaAs and InGaAsP diode laser in the 70s leads to the development of modern optical fibre communication system with 1.3urn and 1.55um, which promotes the rare-earth doped device development [3]. Semiconductor optical amplifier is verified experimentally, which can increase the receiver sensitivity (as the preamplifier) or transmission length (as a repeater), also can realize multiple amplification in a communication system. However, the nonlinear effects of signal-mode have been widely concerned in the meantime (e.g. Raman scattering, Brillouin is scattering and four-wave mixing); these nonlinear effects can have a potential to realize signal amplification, to help the standard quartz matrix fibre become amplification medium [4].

For different optical fibre substrates, the ways of doping are various, including two aspects: quartz matrix doped fibre and glass matrix doped fibre. As for the former, Won-Taekhan et al from South Korea Gwangju Institute of Science and Technology use MVCD method, combining solution immersion with high-temperature processing, and applying traditional physical adsorption doping technique for preparing optical fibre, doping PbTe nano-scale semiconductor compounds in fibre, its amplified spontaneous emission can be achieved in waveband of 1537nm. Recent researched about optical fibre doping by using MVCD method, including doped InP nano-particle in silica fibre cladding, radiation wavelength of 1080-1350nm and Lipu light of 532mn. For the latter, glass matrix doping, as the glass matrix of transmission optical signals, generally can be divided into four types, namely oxide glass, halide glass, oxide glass and

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chalcogenide glass. According to these amplified fibres with different matrixes doping nano-scale semiconductor materials, many research groups have achieved good results. Therefore, some related studies can judge that, in order to meet the demand of bandwidth and optical amplifier gains, the doped sources are advanced from rare-earth elements to nano-scale semiconductor materials, and doped matrixes also have silica fibre, glass fibre, photonic crystal fibre and so on. It also can judge the research for further amplification fibre, mainly focusing on amplified fibre using nano semiconductor materials as doped sources.

2 The preparation of optical fibre doped with InP nano-scale materials

InP nano-scale materials-doped optical fibre in this paper is mainly realized by MVCD method [5].

2.1 PREFORM FABRICATION

Here, we use MVCD method, successfully fabricating two new structures of optical fibre, namely InP nano-particle-doped fibre and fibre of InP nano inner cladding. The preform fabrication of these two fibres is presented in Table 1.

TABLE 1 Optical fibre preform fabrication method

InP nano-particle-doped fibre	**Fibre of InP nano inner cladding**
1. The first step is to make the core rod: filling the fixed reaction tube with halide $SiCl_4$, C_2F_6 steam and mixed gases of InP materials without heating vaporization by using N_2. As previous said that mixed gases moves towards the direction of principle axis, using oxy-hydrogen flame to form dust through chemical vapour reaction, and the dust (the generated oxides, e.g. SiO_2) is deposited in tube walls, finally sintering shrinkage quartz tube to form solid core rod. 2. The second step is cladding frication: similarly as before, placing the quartz tube on the lathe, putting $SiCl_4$ into the quartz tube by oxygen with maintained high-temperature conditions for depositing outsourcing layer of SiO_2, and then adjusting the flow rate of C_2F_2 to control cladding index, the principle of which has been discusses in the previous section; 3. The third step is to insert the finished solid core pf step 1 to the deposited quartz tube of step 2, fixed in the lathe; it can fill inert gas in this process to prevent oxidation of the deposited particles; 4. Finally, heating the mixed quartz tube of step 3, to make the quartz tube collapse into an optical fibre perform with doped InP, preparing the next step of wiredrawing.	1. The first step is to make the core rod: filling the fixed quartz tube with halide $SiCl_4$ and C_2F_6 steam for chemical vapour deposition at a high temperature, and sintering the quartz tube with SiO_2 tectorium under the reaction of $SiCl_4(G)+O_2(G)$-> and $SiO_2(S)+2I_2(G)$ at high temperature to be solid core rod; 2. The second step is that with the gasification of heat light, it fills with the same reaction gas as the step 1, using same method to deposit loose outer layer of SiO_2 in quartz tube; 3. The third step is to change the conveying gas of the second step to inert gas for transporting InP steam, depositing InP film sediments in the loose layer of SiO_2; 4. The fourth step is to insert the core rod of step 1 to the deposited quartz tube of step 3 with the maintained high temperature and inert gas in the process; 5. Finally, heating to a suitable temperature, to make the quartz tube of step 4 collapse into a preform for the next step of wire drawing.

2.2 THE WIREDRAWING OF INP NANO-PARTICLE-DOPED FIBRE

These two kinds of optical fibres with the same drawing convey the preform to the heating furnace with a certain speed and uniform, controllable manner by using feeder, and drawing general fibres need to be heated to 2000℃. The degree of rod is decreased, relying on its own weight gradually tapering into fibres, and using accurate mechanical control to draw the dissolved preform to fibre. The main components of optical fibre drawing machine include conveying preform, heating devices, controlling assembly of wiredrawing diameters, the parts of coating fibre, curing fibre components, traction wheel, winding and other control units. Laser diffraction light of fibre diameters ejected from the fibre can change the distraction pattern by optical controlling diameter variations, successively changing the photodiode. This immediate change will be in a form of signals, passing to servo control machinery for adjusting the speed of winding fibre. Fibre diameter variations can rely on this technique to stability control within 0.1%. As a control factor in drawing, it needs to consider the tension of all components in doping fibre, and keep drawing balanced with controllability; while ensuring all parts of doped InP materials without breakage and volatilization, it leads to the affected part undoped InP nano-materials, and drawing should choose a relatively temperature of 1600-170 (with an appropriate speed of less than 5m/min [6]. The typical value of wrapped fibre diameter is 250 um, and it can be increased to 900 um with multiplayer package.

2.3 INTEGRATION SCHEME WITH ALD TECHNOLOGY

Through the above analysis, it has been successfully drawing the required doped fibres, to further improve the characteristics of optical fibre and advance the drawing, which can consider the combination of MVCD and atomic layer deposition (ALD) technologies, to be improved, as shown in Figure 1.

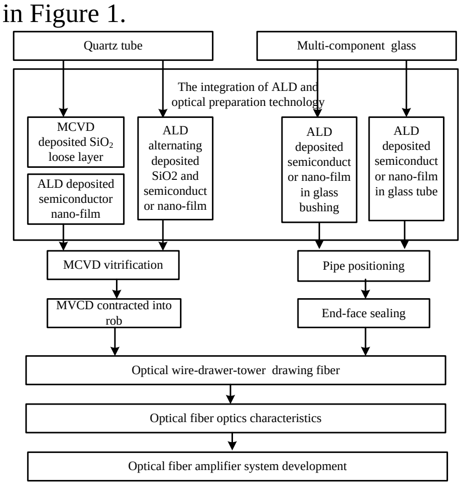

FIGURE 1 the integrated study of MVCD and ALD

For the purpose of the study, we mainly adopt the scheme that after depositing SiO_2 with general MVCD, it uses ALD to wrap the doped semiconductor materials in the surface of loose body with the form of atomic layer, and then uses MVCD to vitrify the loose body; in this process with high temperature, the doped source in atomic layer diffuses and splits material structures of SiO_2, to realize the nano-scale semiconductor doping, but due to the large surface of loose body, thus this scheme has high efficiency of doping.

2.4 NANO-SCALE SEMICONDUCTOR DOPED WITH SILICA FIBRE PREFORMS

In MVCD, by controlling the parameters including tube pressure, flow rate, glass transition temperature and head movement speed, it can acquire different semiconductor doped fibre matrix materials, using a variety of testing methods, such as XRD, SEM, TEM, absorption spectrum, Raman spectrum and so on, to analyse the obtained verification doped layer and then adjust and optimize technological parameters. After verification of doped loose body, collapsing into rod through base tube, it uses preform to analyse refractive index distributions of system testing preform, and acquire the material samples in doped area of preform by grinding and particle beam reduction, then analysing its microstructure characteristics, in order to achieve phase transition properties with high temperature of doped fibre waveguide matrix. According to the highly volatile of nano-scale semiconductor at high temperature, it can be settled down through the following techniques:

1. selecting different precursors of Lead, increasing the solubility of doped materials in SiO2 structures to improve the concentration;
2. using ALD to alternating deposit semiconductor doped sources and other oxides, to form a protective layer in the surface of semiconductor atomic layer, so as to improve the doping concentration and avoid volatile;
3. using ALD technology first to dope the nano-scale semiconductor into the loose layers, and then using MVCD to deposit SiO2 as a protective layer;
4. tubes with protective gas during the vitrification, for instance, avoiding sulfur volatilization can access sulfur-containing to restrain its diffusion volatility.

While in drawing, preform diameter is greatly reduced, and the film thickness of semiconductor in substrate interface is sharply decreased. Which is because semiconductor film is pulled by axial drawing is a molten state to form flow diffusion, resulting in the ruptures of film, surface shrinkage and semiconductor particles changing from condensate to nano-cluster, so as to form nano-scale semiconductor particles between the core and cladding of the fibre. Through the adjustment of wire temperature and drawing speed, it can control the scale of nano-scale semiconductor with its distribution, improving amplifier efficiency and reducing the loss.

3 The analysis of doped fibre characteristics

3.1 MATERIALS DISPERSION

The emergence of material dispersion is due to the different material for producing optical fibre, and refractive index changes with the light impulse frequency. According to the root causes, when materials absorb electromagnetic radiation, raw materials dispersion is relative to intrinsic resonant frequency. However, it has nothing to do with the materials resonance, the refractive index expressed as Sellmeier Equation [7]:

$$n^2(\omega) = 1 + \sum_{j=1}^{M} \frac{B_j \omega_j^2}{\omega_j^2 - \omega^2}, \tag{1}$$

where, ω_j represents the resonant frequency of material, β_j oscillation intensity. n stands for n_1 or n_2, depending on the dispersion characteristics belonging to core or cladding [1]. The calculations and results contain all materials of resonance characteristics, relying on frequency. As for optical fibres, analysing filtration by characteristic curve, the parameters β_j and ω_j can get the empirical value $M = 3$.

Simply assuming the impulse as plane wave, only considering the effects of materials dispersion, and based on this can ignore the influences of waveguide dispersion, it can use Equation (2) to represent the group delay τ:

$$\tau(\omega) = \frac{d\beta}{d\omega}, \tag{2}$$

where, β presents the transmission constant of plane wave, ω angular frequency of the light, and $\beta = \omega n(\omega)/c$, $n(\omega)$ for refractive index and C for the speed of light in vacuum. It can obtain that:

$$\tau(\omega) = \frac{1}{c}\left[n(\omega) + \omega \frac{dn(\omega)}{d\omega}\right]. \tag{3}$$

Substituting $\lambda = 2\pi c/\omega$, then:

$$\tau(\omega) = \frac{1}{c}\left[n(\lambda) - \lambda \frac{dn(\lambda)}{d\lambda}\right]. \tag{4}$$

The dispersion parameter is:

$$D = \frac{d\tau}{d\lambda} = -\frac{\lambda}{c}\frac{d^2 n}{d\lambda^2} \text{ (Ps/km/nm)}. \tag{5}$$

3.2 WAVEGUIDE DISPERSION

Any lights transmission in optical fibre, its group velocity varies with optical wavelength, called as waveguide dispersion [8]. To determine the structure parameters by fibre refractive index distribution is the main cause of waveguide dispersion. At the meantime, different light modes transmitted in optical fibre will lead to the various waveguide dispersions. The sum of different patterns of waveguide dispersions in optical fibre shall be the waveguide dispersion of multimode fibre. To analyse waveguide dispersion can start from the group velocity. Considering the length of single mode fibre (SMF) as L, when light frequency is ω, and fibre transmission reaches the end, with the transmission time as $T = L / v_g$, while v_g represents group velocity, it can be defied as:

$$v_g = \left(d\beta / d\omega\right)^{-1}, \quad (6)$$

where propagation constant $\beta = \bar{n}k_0 = \bar{n}\omega / c$, the group velocity can be expressed as $v_g = c / \bar{n}_g$, while $\bar{n}_g$ stands for group refractive index:

$$\bar{n}_g = \bar{n} + \omega\left(d\bar{n} / d\omega\right). \quad (7)$$

Supposing $\Delta\omega$ as impulse frequency bandwidth, the impulse bandwidth when optical length is L should be:

$$\Delta T = \frac{dT}{d\omega}\Delta\omega = \frac{d}{d\omega}\left(\frac{L}{v_g}\right)\Delta\omega = L\frac{d^2\beta}{d\omega^2}\Delta\omega = L\beta_2\Delta\omega, \quad (8)$$

where $\beta_2 = d^2\beta / d\omega^2$ expresses group velocity dispersion parameters, which indicate the broadening degree of optical impulse in transmission. In some optical communication systems, the frequency bandwidth $\Delta\omega$ is determined by the width of emission wavelength $\Delta\lambda$. Therefore, it generally uses $\Delta\lambda$ instead of $\Delta\omega$, introducing $\omega = 2\pi c / \lambda$ and $\Delta\omega = (-2\pi c / \lambda^2)\Delta\lambda$ to the Equation (8) can obtain:

$$\Delta T = \frac{d}{d\lambda}\left(\frac{L}{v_g}\right)\Delta\lambda = DL\Delta\lambda, \quad (9)$$

where:

$$D = \frac{d}{d\lambda}\left(\frac{L}{v_g}\right) = -\frac{2\pi c}{\lambda^2}\beta_2. \quad (10)$$

For the convenient analysis below, the dispersion parameter D is expressed as the above equation, with the unit ps/km/nm. Thus, it can be concluded that the dispersion parameter D relying on wavelength variations is composed by refractive index $\bar{n}$ of the mode depending on frequency. For the above, it can get:

$$D = -\frac{2\pi c}{\lambda^2}\frac{d}{d\omega}\left(\frac{1}{v_g}\right) = -\frac{2\pi c}{\lambda^2}\left[2\frac{d\bar{n}}{d\omega} + \omega\frac{d^2\bar{n}}{d\omega^2}\right]. \quad (11)$$

Thus, it can express D as the sum of two items:

$$D = D_M + D_W, \quad (12)$$

where D_m stands for the detail expression of material dispersion, D_w for waveguide dispersion, which can obtain respectively:

$$D_M = -\frac{2\pi}{\lambda^2}\frac{dn_{2g}}{d\omega} = \frac{1}{c}\frac{dn_{2g}}{d\lambda}, \quad (13)$$

$$D_W = -\frac{2\pi\Delta}{\lambda^2}\left[\frac{n_{2g}^2}{n_2\omega}\frac{Vd^2(Vb)}{dV^2} + \frac{dn_{2g}}{d\omega}\frac{d(Vb)}{dV}\right]. \quad (14)$$

While, n_{2k} presents group refractive index of the cladding:

$$V = k_0 a\left(n_1^2 - n_2^2\right)^{\frac{1}{2}} \approx \left(2\pi / \lambda\right)an_1\sqrt{2\Delta},$$

$$b = \frac{p / k_0 - n_2}{n_1 - n_2} = \frac{n - n_2}{n_1 - n_2},$$

V for normalized frequency, k_0 for free space-wavenumber $k_0 = \omega / c = 2\pi / \lambda a$ while a stands for optical radius, n_1 and n_2 for fibre core and cladding refractive index respectively, and $\Delta = \left(n_1 - n_2\right) / n_2$ for relative refractive index unrelated to frequency, b for normalized transmission constant [9].

3.3 THE ANALYSIS OF SINGLE-MODE OPTICAL DISPERSION

In order to analyse the simplification of the model, it can take the effect of removing mode distortion, thus setting single mode fibre as the ideal single mode fibre with circular symmetry, where the optical dispersion can be simplified as the derivative of group delay to wavelength, while dispersion is a major cause of impulse broadening. Supposing refractive index as:

$$n^2(r) = n_2^2\left[1 + 2\Delta f\left(\frac{r}{a}\right)\right], \quad (15)$$

where, $f\left(\frac{r}{a}\right)$ represents distribution function of refractive index and $0 \le V\left(\frac{r}{a}\right) \le 1$.

The wave equation of wave light transmitting in optical fibre is shown as below:

$$\frac{1}{R}\frac{d}{dR}\left(\frac{Rd\psi}{dR}\right) + \left[V^2 f\left(\frac{r}{a}\right) - V^2 B - \frac{m^2}{R^2}\right]\psi = 0. \quad (16)$$

While, $\psi\left(\frac{r}{a}\right)$ stands for radial variable Eigen function of the wave light, and $R = \frac{r}{a}$, m for radical mode number, $V = ka\left(n_1^2 - n_2^2\right)^{V_2}$, and B for normalized transmission constant, which can be defined as:

$$B = \left(\beta^2 / k - n_2^2\right) / \left(n_1^2 - n_2^2\right). \quad (17)$$

While, N_1, N_2 are expressed as the group refractive index of n_1 and n_2, namely:

$$N_1 = n_1 - \lambda\left(dn_1 / d\lambda\right), N_2 = n_2 - \lambda\left(dn_2 / d\lambda\right), k = 2\pi / \lambda .$$

Equation (17) can be simplified based on the weak-guide as:

$$B = \frac{\beta - kn_2}{kn_2\Delta} . \tag{18}$$

Using Equation (17) for the derivation of *k*:

$$\frac{d\beta}{dk} = N_2 + \left(N_1 - N_2\right)\frac{d\left(VB\right)}{dV} . \tag{19}$$

The group delay of unit length is:

$$\tau = \frac{d\beta}{d\omega} = \frac{1}{c}\frac{d\beta}{dk} . \tag{20}$$

Thus:

$$\tau = \frac{N_2}{c}\left[1 + \frac{N_1 - N_2}{N_2}\frac{d\left(VB\right)}{dV}\right] \approx \frac{N_2}{c}\left[1 + \Delta\frac{d\left(VB\right)}{dV}\right].$$

This can reach the dispersion parameter *D*:

$$D = \frac{d\tau}{d\lambda} = M_2\left[1 + \Delta\frac{d\left(VB\right)}{dV}\right] - \frac{N\Delta}{\lambda c}\left[V\frac{d^2\left(VB\right)}{dV^2} - P\frac{d\left(VB\right)}{dV}\right], \tag{21}$$

where, $M_2 = \frac{1}{c}\frac{dN_2}{d\lambda}$ expresses material dispersion, which can obtain $M_2 = \frac{1}{c}\frac{d^2 n_2}{d\lambda^2}$, $\mathrm{P} = \frac{\lambda}{\Delta}\frac{d\Delta}{d\lambda}$ as profile dispersion parameter.

It can be seen from the equation of dispersion parameter *D* in Equation (21) that the first term of the equation at the right is material dispersion. The second item is waveguide dispersion, and it can been seen from the parameters of the expression that two items both contain optical structure parameter *V* which represents the characteristic parameter of material dispersion, relative to the material dispersion as a whole. From the above equations, it can use the numerical calculation of wave equation in optical fibre can calculate the relation curve between normalized transmission constant *B* and optical structure parameter *V* under the different modes of light transmissions, further introducing material dispersion M_2 can get the corresponding values of dispersion parameter *D* in different transmission modes. According to the previous analysis of simplified calculations, as for ideal single mode fibre with circular symmetry $m = 0$, it can simplify the previous wave equation of optical transmission light for calculation.

When optical transmission bit rate is *R*, the effect of its dispersion can estimate by the principle of $R\Delta T < 1$, while ΔT is the maximum multipath time delay of light transmission with transmission length *L*, and $\Delta \mathrm{T} = DL\Delta\lambda$, $\Delta\lambda$ corresponding to $\Delta\omega$ and $\Delta\omega$ for the bandwidth of light wave frequency. Based on the above analysis, the effect of dispersion on optical fibre transmission can be clearly expressed as criteria $RL\left|D\right|\Delta\lambda < 1$. Aiming at single mode fibre with size of *RL*, it can estimate an order of magnitude of dispersion parameter by the criteria, to evaluate its dispersion characteristics. And for a standard silica fibre, the dispersion parameter *D* around the range of wavelength with 1.3 μm is relatively small (*D* – lps/km/nm). For semiconductor lasers, even operating on several longitudinal modes, the spectrum width $\Delta\lambda$ is only 2-4 nm. The product of bit rate and optical length in this light-wave system *RL* can exceed 100(Gb/s) km. And actually, the typical bit rate of communication system of length 1.3 μm is 2Gb/s, regenerated length of 40-50 km. While applying single-mode semiconductor lasers, the product of single-mode fibre bit rate and optical length can exceed l (Tb/s) km, and now the spectrum width $\Delta\lambda$ will be smaller than 1 nm.

3.4 DISPERSION ANALYSIS OF DOPED INP NANO-PARTICLE OPTICAL FIBRE

The application of drawing amplifier fibre in this paper in real optical devices needs to analyse its dispersion characteristics to identify its impact on the system, this dispersion analysis fixed in the wavelength range of 1200-1600 nm.

The expression of dispersion parameter *D* is presented as below:

$$D = -\frac{2\pi c}{\lambda^2}\beta = -\frac{\lambda}{c}\frac{d^2 n}{d\lambda^2} . \tag{22}$$

From the right side of the equation, it can judge that *D* associates with the refractive index [10], therein β_2 stands for group velocity dispersion, *c* for light speed in vacuum. The relation curve of dispersion parameter and wavelength is shown as Figure 2.

Due to the dispersion effects, various frequency components of optical pulse in optical fibre transmission have differences. When the parts of low frequency is faster than high frequency, then the light pulse lies in the normal dispersion region of the optical fibre, namely $\beta_2 > 0$; when high frequency is faster than the low frequency, then the light pulse locates in the abnormal dispersion region, namely $\beta_2 < 0$, which is achieved by the basic definition of normal dispersion and abnormal dispersion. Looking back to the Figure 2, the horizontal line in the diagram represents zero dispersion, and dash curve stands for the relations between the dispersion parameter and wavelength of undoped common single mode fibre, while solid curve expresses the relations between dispersion parameter and wavelength of single mode fibre with doped InP nano-scale semiconductor materials. It can be seen clearly from the Figure that, as zero dispersion of undoped common single mode fibre lies in λ_D = 1312 nm. When the wavelength $\lambda < \lambda_D$ namely it is less than 1312 nm. On the left side of intersection between dashed lines and black lines which shows the undoped common single mode fibre lies in the normal dispersion region with low frequency faster than high frequency. On the right side after the higher than zero dispersion, which high frequency of fibre is faster than the low frequency of abnormal dispersion range. As for the single mode fibre with doped InP nano-scale semiconductor materials, from the wavelength range of 1200-1600 nm as shown in solid curve (below), dispersion parameter is less than zero all the time and positively correlated with wavelength changes, besides, it also shows a normal dispersion of low frequency faster than high frequency transmission. The single mode fibre after doping InP nano-scale semiconductor materials, the performance of its dispersion parameter varies from dashes lines from solid lines, and nano-doped materials make the dispersion parameter curve change down, the main reason of which is the special properties of nano-materials, generating fundamental changes in the dispersion of single mode fibre materials [11]. This fundamental change will be discusses as below, with its main factor derives from quantum effect of nano materials, affecting the optical fibre itself. Compared nano-InP materials with block InP materials, its absorption peak has a blue shift, owing to the doped drawing fibre to affect the absorption peak.

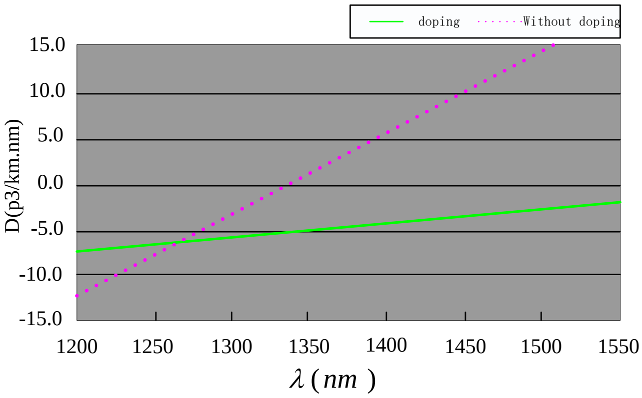

FIGURE 2 Curve of dispersion parameter *D* changing with wavelength

3.5 OPTICAL AMPLIFICATION CHARACTERISTICS

Transmission length is often limited by fibre loss for any optical fibre communication system [12]. And for long distance transmission system, confinement loss is usually overcome by photoelectric conversion, firstly converting optical signals into electric signals, and then regenerated into optical signals by transmitter [13]. This regenerator will be very complex and expensive to WDM optical system. Thus, another optical amplifier is an important way to overcome this loss, but such a method is to amplify optical signal itself without transferring optical signal into electrical signal [14]. Some specific discussions about fibre amplifiers have been held before, which can be judged that the amplification properties of doped InP particles fibre in this study will become important references for producing optical fibre amplifiers [15].

Most of optical amplifiers enlarge the incident light by stimulated radiation, which is similar with the structures and principles of lasers. Actually, a fibre amplifier is only a laser without feedback. While amplifiers realizing population inversion by pumping (light or electricity), it realizes the important function of its optical gain. In general, the optical gain not only depends on the frequency of incident light (or wavelength), but also associates with local intensity insider the amplifier. The detail analysis of optical gain frequency dependent and intensity dependent is related to the amplification medium inside the optical amplifiers, and generally, considering gain medium as model for homogeneous broadening. This gain coefficient of the medium is:

$$g(\omega) = \frac{g_0}{1+(\omega-\omega_0)T_2^2 + P/P_s}, \quad (23)$$

where, g_0 represents peak gain, ω incident signal light frequency, ω_0 for atomic jump frequency and p for amplified signal light power. The saturation power p relies on gain medium parameters including burst time and transition process, etc. Parameter T_2 stands for dipole relaxation time with its typical value lower than 1 ps. Burst time T_1 is also known as population relaxation time, varying in 100ps-10ns and relying on gain medium. It can use the above equations to discuss some important features of optical amplifiers, such as gain bandwidth, amplification coefficient, output saturated power and so on. Considering the optical amplifiers under unsaturated conditions, leaving out P/P_s, the gain coefficient can be expressed as:

$$g(\omega) = \frac{g_0}{1+(\omega-\omega_0)T_2^2}. \quad (24)$$

The equation indicates that when incident frequency ω is consistent with atomic jump frequency ω_0, the gain coefficient can reach the maximum. Gain bandwidth can be defined as half-high bandwidth of gain spectrum $g(\omega)$. As for Lorentz line, the gain bandwidth is presented by $\Delta\omega_g = 2/T_2$, or:

$$\Delta v_g = \frac{\Delta\omega_g}{2\pi} = \frac{1}{\pi T_2}, \quad (25)$$

amplifies with an appropriate size of bandwidth is quite important for optical communication system. This is because even for a multi-channel signal, the gain is continuous over the entire bandwidth seems very important. The concept of amplifier bandwidth often alternates the notion of gain bandwidth. While considering the amplifier gain *G*, the difference will be more distinct. The measurement of amplifier gain that widely used is presented as below, thus the amplification coefficient can be defined as:

$$G = P_{out} / P_{in}, \quad (26)$$

where, P_{in} and P_{out} represent the input and output power of amplified continuous wave signal, respectively. And then, the expression of *G* can be obtained:

$$\frac{dP}{dz} = gP, \quad (27)$$

while, *P*(1) expresses the optical power from input terminal to the distance *Z*. Using original state of $P(0) = P_{in}$ to directly integrate to achieve the expression of signal power changing with index:

$$P(z) = P_{in}\exp(gz). \quad (28)$$

According to $P(L) = P_{out}$ it can reach the relationship between amplification coefficient and distance *L* as:

$$G(\omega) = \exp\left[g(\omega)L\right]. \quad (29)$$

It uses the ratio of input optical power and output optical power to the following tests, so as to measure the amplification characteristics, realizing the optical amplifier bandwidth of the fibre to be measured.

The following steps are to determine the optical amplification features of fibres with drawing InP nano-scale materialsThe working system consists of several parts, including fibre amplifier inside InP nano-film cladding, two wavelength division multiplexers (WDM), pump light source, signal source and output terminals, and between the two WDM is the fibre with InP nano materials to be measure for determining amplification characteristics, pump light entering into the fibre for its optical pumping by coupling of WDM. From the above tests, it shows in Figures 4 and 5. that there have gains in the wave band of 906-1044 nm, 1080-1491 nm and 1524-1596 nm.

3.6 TESTS ON THE GENERATION OF SUPER-CONTINUUM

Super-continuum system as shown in Figure 3, it uses a 120fs passive mode-locking laser with 1550 nm of central wavelength and repetitive rate of 50MHZ as light pulse to be amplified by EDFA, and then inputted into the fibre with InP nano-film cladding. At the output terminal of the fibre, the light beam is divided into two parts by beam splitter with ratio of 1:9, while 90% of light power is inputted into the power meter, and 10% of them are inputted into the spectrum analyser (YOKOGAWA-AQ6370), so as to measure the output spectra. In order to facilitate connecting with conventional fibre and be conductive for optical power to couple into the fibre, the two terminals of InP nano-film cladding will be connected with two transition fibres with length of 1m.

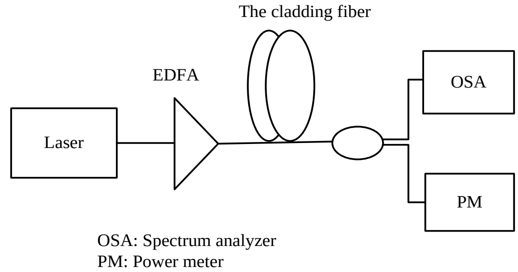

FIGURE 3 Super-continuum system

The input power is 21.3dBm, the cladding fibre doped nano-scale semiconductor will generate super-continuum spectrum and the fibre length is 30cm and 90cm respectively, as shown in Figures 4 and 5.

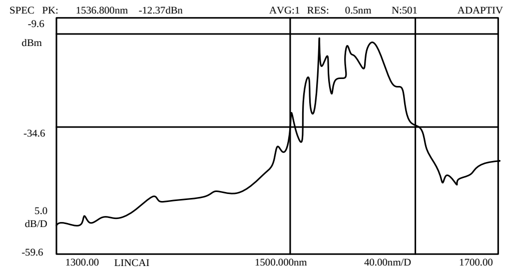

FIGURE 4 Super-continuum spectrum of fibre length 30cm

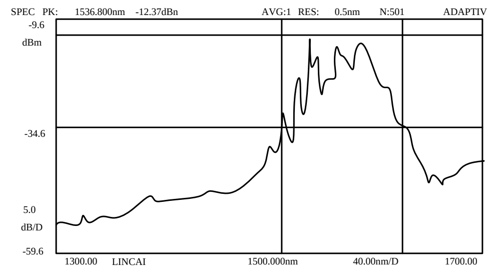

FIGURE 5 Super-continuum spectrum of fibre length 90cm

Figure 4 shows that the fibre length of 30cm acquires 20dB pulse bandwidth of 140 nm. Under the same condition, the measured fibre length of 90cm acquires 20dB pulse bandwidth of 175 nm. The results indicate that the fibre length is longer, and the pulse bandwidth is greater, optical non-linear effects more obvious.

4 Conclusion

This paper mainly studies for the amplification fibre of doped nano-scale semiconductor materials. Firstly, it successfully produces two new structures of optical fibre based on MCVD, and analyse the optical characteristics of amplifies fibre. The appearance of optical fibre amplifier well solves the relay amplification of optical signal in optical transmission system with long distance, high speed and large-capacity backbone network, and amplifies optical fibre as the core part of fibre amplifier will be a focus, while the study on fibre amplifier of nano-scale semiconductor material as doping source will be the main direction and focus of communication optical fibre in the future.

CFX module can ensure accuracy and stability of calculation result as well as basic conservation characteristics and accuracy of numerical value. Pre-processing of 3-D geometric model mainly involved functional operation in DesignModeler on model that have been imported to realize the modelling process of rotating field and external flow field. Through pre-processing of windmill 3-D geometric model by ANSYS Workbench, we used Mesh module to divide the mesh of windmill 3-D geometric model to generate the needed calculation mesh. After division of windmill 3-D geometric model mesh, we entered into fluid analysis setting including designing boundary condition and properties of solver. We only need to do simple solver setting after calculation of fluid and then solution result could be achieved. At last, the numerical simulation of aerodynamic characteristics of windmill was achieved.

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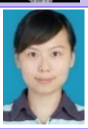

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