

# 强双折射光纤中任意偏振方向矢量调制不稳定性\*

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利用光脉冲在非线性双折射光纤中传播时所遵循的相干耦合非线性薛定谔方程, 研究了偏振方向与双折射轴成任意角度时, 在反常色散区和正常色散区所产生的调制不稳定性. 结果表明, 在反常色散区和正常色散区存在不稳定偏振区域和稳定偏振区域, 对应不同的不稳定偏振区域, 输入临界功率不同, 脉冲有不同的增益谱.

关键词: 任意偏振方向, 矢量调制不稳定性, 非线性光纤, 双折射

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## 1. 引言

当一连续波在非线性介质中传输时, 由于非线性和色散的相互作用, 产生调制不稳定性. 在弱的噪声和其他一些小的微扰存在时, 由于振幅和相位的调制, 连续波最终被分裂成高重复率的超短脉冲, 从而产生光孤子<sup>[1,2]</sup>. 当一连续波入射到双折射光纤中, 将同时激发两种偏振成分, 产生矢量调制不稳定性. 在弱双折射光纤中, 当输入光波的偏振方向沿着快轴或慢轴时, 由于光纤的双折射, 并通过光纤中的非线性, 发生相互作用, 产生交叉相位调制(XPM), 不仅在反常色散区产生调制不稳定性, 而且在正常色散区也能产生调制不稳定性<sup>[3,4]</sup>. 在高双折射光纤中, 当入射一连续波, 其偏振方向与慢轴成 45° 时, 由于双折射、非线性效应和色散的相互作用, 产生交叉相位调制, 也可产生调制不稳定性<sup>[5-9]</sup>, 导致相位匹配参量的四波混频<sup>[7]</sup>. 本文利用相干耦合非线性薛定谔方程, 研究了偏振方向与双折射轴成任意角度时不同的偏振方向、不同功率区域的调制不稳定性.

## 2. 理 论

光脉冲在非线性双折射光纤中传输时所遵循的相干耦合非线性薛定谔方程为

$$\frac{\partial E_1}{\partial z} - \frac{\delta}{2} \frac{\partial E_1}{\partial t} + i\beta_2 \frac{\partial^2 E_1}{\partial t^2} - i\gamma \left( |E_1|^2 + \frac{2}{3} |E_2|^2 \right) E_1 = 0, \quad (1a)$$

$$\frac{\partial E_2}{\partial z} + \frac{\delta}{2} \frac{\partial E_2}{\partial t} + i\beta_2 \frac{\partial^2 E_2}{\partial t^2} - i\gamma \left( |E_2|^2 + \frac{2}{3} |E_1|^2 \right) E_2 = 0, \quad (1b)$$

式中  $E_1, E_2$  为沿着快轴和慢轴偏振的场的慢变包络,  $\beta_2$  为群速度色散,  $\gamma = \frac{n_2 \omega}{cA_{\text{eff}}}$  ( $n_2$  为非线性折射率系数),  $A_{\text{eff}}$  为有效截面,

$$\delta = \frac{1}{v_{\text{gy}}(\omega_2)} - \frac{1}{v_{\text{gx}}(\omega_1)}$$

为群速度失配, 它依赖于光纤的双折射, 可近似表示为

$$\delta_0 = \frac{B}{c}, \quad (2)$$

$B = n_y - n_x$  为光纤的固有双折射.

现在考虑没有损耗的强双折射光纤, 光波沿着  $z$  轴传播,  $x$  轴为双折射轴中具有较低折射率的快轴,  $y$  轴为慢轴, 设输入光的偏振方向与  $x$  轴成  $\alpha$  角, 输入光的功率为  $P$ , 则

$$P_x = P \cos \alpha, \quad P_y = P \sin \alpha.$$

方程(1)的稳态解为

$$E_1 = \sqrt{P_x} \exp \left[ i\gamma \left( P_x + \frac{2}{3} P_y \right) z \right],$$

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$$E_2 = \sqrt{P_y} \exp\left[i\gamma\left(P_y + \frac{2}{3}P_x\right)z\right]. \quad (3)$$

(3) 式中引入一阶微扰项  $u$  和  $v$  , 得

$$\begin{aligned} E_1 &= (\sqrt{P_x} + u) \exp\left[i\gamma\left(P_x + \frac{2}{3}P_y\right)z\right], \\ E_2 &= (\sqrt{P_y} + v) \exp\left[i\gamma\left(P_y + \frac{2}{3}P_x\right)z\right]. \end{aligned} \quad (4)$$

将(4)式代入(1)式, 线性化后得到有关  $u$  和  $v$  的方程,

$$\begin{aligned} \frac{\partial u}{\partial z} - \frac{\delta}{2} \frac{\partial u}{\partial t} + i\beta_2 \frac{\partial^2 u}{\partial t^2} - i\gamma P_x (u + u^*) \\ - i\gamma \frac{2}{3} \sqrt{P_x P_y} (v + v^*) = 0, \end{aligned} \quad (5a)$$

$$\begin{aligned} \frac{\partial v}{\partial z} + \frac{\delta}{2} \frac{\partial v}{\partial t} + i\beta_2 \frac{\partial^2 v}{\partial t^2} - i\gamma P_y (v + v^*) \\ - i\gamma \frac{2}{3} \sqrt{P_y P_x} (u + u^*) = 0. \end{aligned} \quad (5b)$$

设

$$u = u_s \exp[i(\Omega t - Kz)] + u_a \exp[i(-\Omega t + Kz)], \quad (6a)$$

$$v = v_s \exp[i(\Omega t - Kz)] + v_a \exp[i(-\Omega t + Kz)], \quad (6b)$$

将(6)式代入(5)式, 得到有关  $u_s, u_a, v_s, v_a$  的线性方程, 得到如下色散关系:

$$(K^2 - f_1)(K^2 - f_2) = C_{\text{XPM}}, \quad (7)$$

式中

$$f_1 = \left(\frac{1}{2}\beta_2\Omega^2 + \gamma P_x\right)^2 + \left(\frac{1}{2}\delta\Omega\right)^2 - \gamma^2 P_x^2, \quad (7a)$$

$$f_2 = \left(\frac{1}{2}\beta_2\Omega^2 + \gamma P_y\right)^2 + \left(\frac{1}{2}\delta\Omega\right)^2 - \gamma^2 P_y^2, \quad (7b)$$

$$\begin{aligned} C_{\text{XPM}} &= \left(\frac{2}{3}\right)^2 \beta_2^2 \Omega^4 \gamma^2 P_x P_y + \frac{1}{4} \beta_2^2 \delta^2 \Omega^6 \\ &+ \frac{1}{2} \beta_2 \delta^2 \gamma \Omega^4 (P_x + P_y). \end{aligned} \quad (7c)$$

方程(7)的解为

$$\begin{aligned} K^2 &= \frac{1}{2} \{ (f_1 + f_2) \pm [(f_1 + f_2)^2 + \mathcal{X} C_{\text{XPM}} - f_1^2] \\ &+ \mathcal{X} C_{\text{XPM}} - f_2^2 \}^{1/2}. \end{aligned} \quad (8)$$

这个解表明, 当  $2C_{\text{XPM}} - (f_1^2 + f_2^2) > 0$  时,  $K^2$  有负值, 稳态解变得不稳定, 由  $2C_{\text{XPM}} - (f_1^2 + f_2^2) > 0$  得

$$(\Omega^2 - \Omega_+^2)(\Omega^2 - \Omega_-^2) < 0, \quad (9)$$

式中

$$\Omega_+^2 = \frac{\delta^2}{\beta_2^2} - \frac{2\gamma(P_x + P_y) \text{sgn}(\beta_2)}{|\beta_2|}$$

$$\begin{aligned} &+ \frac{1}{2} \left\{ \frac{25 \times 32}{9} \frac{\gamma^2}{\beta_2^2} P_x P_y - \frac{16\gamma^2}{\beta_2^2} (P_x^2 + P_y^2) \right\}^{1/2} \\ &= \frac{\delta^2}{\beta_2^2} - \frac{2\gamma P (\cos\alpha + \sin\alpha) \text{sgn}(\beta_2)}{|\beta_2|} \\ &+ \frac{1}{2} \left\{ \frac{25 \times 32}{9} \frac{\gamma^2}{\beta_2^2} P^2 \cos\alpha \sin\alpha - \frac{16\gamma^2}{\beta_2^2} P^2 \right\}^{1/2}, \end{aligned} \quad (10a)$$

$$\begin{aligned} \Omega_-^2 &= \frac{\delta^2}{\beta_2^2} - \frac{2\gamma P (\cos\alpha + \sin\alpha) \text{sgn}(\beta_2)}{|\beta_2|} \\ &- \frac{1}{2} \left\{ \frac{25 \times 32}{9} \frac{\gamma^2}{\beta_2^2} P^2 \cos\alpha \sin\alpha - \frac{16\gamma^2}{\beta_2^2} P^2 \right\}^{1/2}. \end{aligned} \quad (10b)$$

定义  $g(\Omega) = 2I_m(K)$ ,  $g(\Omega)$  代表频率  $\omega_0 \pm \Omega$  对于原始频率  $\omega_0$  的偏移  $\Omega$  后的扰动的增益. 当  $\Omega$  满足(9)式时, 调制不稳定性存在, 对应的增益为

$$\begin{aligned} g(\Omega) &= 2[I_m(K)] = (f_1 + f_2) - [(f_1 + f_2)^2 \\ &+ \mathcal{X} C_{\text{XPM}} - f_1^2] + \mathcal{X} C_{\text{XPM}} - f_2^2 \}^{1/2}. \end{aligned} \quad (11)$$

显然产生调制不稳定性区域和对应的增益与色散区的性质和输入功率  $P$  有关.

## 2.1. 反常色散区

对于反常色散区  $\text{sgn}(\beta_2) = -1$  得

$$\begin{aligned} \Omega_+^2 &= \frac{\delta^2}{\beta_2^2} + \frac{2\gamma P (\cos\alpha + \sin\alpha)}{|\beta_2|} \\ &+ \frac{1}{2} \left\{ \frac{25 \times 32}{9} \frac{\gamma^2}{\beta_2^2} P^2 \cos\alpha \sin\alpha - \frac{16\gamma^2}{\beta_2^2} P^2 \right\}^{1/2}, \end{aligned} \quad (12a)$$

$$\begin{aligned} \Omega_-^2 &= \frac{\delta^2}{\beta_2^2} + \frac{2\gamma P (\cos\alpha + \sin\alpha)}{|\beta_2|} \\ &- \frac{1}{2} \left\{ \frac{25 \times 32}{9} \frac{\gamma^2}{\beta_2^2} P^2 \cos\alpha \sin\alpha - \frac{16\gamma^2}{\beta_2^2} P^2 \right\}^{1/2}. \end{aligned} \quad (12b)$$

对应的增益为

$$\begin{aligned} g_-(\Omega) &= 2[I_m(K)] \\ &= \frac{1}{2} \beta_2^2 \Omega^4 - \beta_2 \Omega^2 \gamma P (\cos\alpha + \sin\alpha) + \frac{1}{2} \Omega^2 \delta^2 \\ &- \left[ \frac{34}{9} \beta_2^2 \Omega^4 \gamma^2 P^2 \cos\alpha \sin\alpha - \beta_2^2 \Omega^4 \gamma^2 P^2 \right. \\ &\left. + \frac{1}{4} \beta_2^2 \delta^2 \Omega^6 - \frac{1}{2} \beta_2 \gamma P \delta^2 \Omega^4 (\cos\alpha + \sin\alpha) \right]^{1/2}. \end{aligned} \quad (12c)$$

由(12a)和(12b)式, 因为  $\Omega_+^2 \geq 0, \Omega_-^2 \geq 0$ , 所以要求

$$\frac{25 \times 32}{9} \frac{\gamma^2}{\beta_2^2} P^2 \cos\alpha \sin\alpha - \frac{16\gamma^2}{\beta_2^2} P^2 \geq 0,$$

解得  $0.18417\text{rad} \leq \alpha \leq 1.38662\text{rad}$ .

根据调制和增益性质的要求,

$$(f_1 + f_2)^2 + 2 C_{\text{XPM}} - f_1^2 + 2 C_{\text{XPM}} - f_2^2 \geq 0,$$

即

$$\frac{34}{9} \beta_2^2 \Omega^4 \gamma^2 P^2 \cos\alpha \sin\alpha - \beta_2^2 \Omega^4 \gamma^2 P^2 + \frac{1}{4} \beta_2^2 \delta^2 \Omega^6 - \frac{1}{2} \beta_2 \gamma P \delta^2 \Omega^4 (\cos\alpha + \sin\alpha) \geq 0,$$

得

$$\Omega^2 \geq \frac{2\gamma P}{\beta_2} (\cos\alpha + \sin\alpha) - \frac{4\gamma^2 P^2}{\delta^2} \left( \frac{34}{9} \cos\alpha \sin\alpha - 1 \right).$$

因为  $\Omega^2 \geq 0$ , 所以要求

$$\frac{2\gamma P}{|\beta_2|} (\cos\alpha + \sin\alpha) - \frac{4\gamma^2 P^2}{\delta^2} \left( \frac{34}{9} \cos\alpha \sin\alpha - 1 \right) \geq 0, \tag{13}$$

解得

$$P \leq \frac{\delta^2 (\cos\alpha + \sin\alpha)}{2\beta_2 \gamma \left( \frac{34}{9} \cos\alpha \sin\alpha - 1 \right)}, \tag{13a}$$

式中  $P$  为输入功率,  $P \geq 0$ .

当

$$\left( \frac{34}{9} \cos\alpha \sin\alpha - 1 \right) > 0,$$

解得  $0.27895\text{rad} (15.98266^\circ) < \alpha < 1.29185\text{rad} (74.01734^\circ)$ .

当

$$\left( \frac{34}{9} \cos\alpha \sin\alpha - 1 \right) < 0, \tag{13b}$$

解得  $0.27895\text{rad} > \alpha > 1.29185\text{rad}$ ,

$$P > \frac{\delta^2 (\cos\alpha + \sin\alpha)}{2\beta_2 \gamma \left( 1 - \frac{34}{9} \cos\alpha \sin\alpha \right)}. \tag{13c}$$

当

$$\left( \frac{34}{9} \cos\alpha \sin\alpha - 1 \right) = 0,$$

此时对于输入任何功率 (13) 式都不满足. 所以当  $\alpha = 0.27895\text{rad}$  或  $1.29185\text{rad}$  时, 不产生调制不稳定性. 并且与光纤的固有双折射  $\delta$ 、群速度色散  $\beta_2$  和非线性系数  $\gamma$  无关.

总结上述结果, 当  $0.27895\text{rad} (15.98266^\circ) < \alpha < 1.29185\text{rad} (74.01734^\circ)$ ,

$$0 \leq P \leq \frac{\delta^2 (\cos\alpha + \sin\alpha)}{2\beta_2 \gamma \left( \frac{34}{9} \cos\alpha \sin\alpha - 1 \right)}$$

时, 产生调制不稳定性.

当  $0.18417\text{rad} \leq \alpha < 0.27895\text{rad}$  或  $1.29185\text{rad} <$

$\alpha \leq 1.38662\text{rad}$ ,

$$P > \frac{\delta^2 (\cos\alpha + \sin\alpha)}{2\beta_2 \gamma \left( 1 - \frac{34}{9} \cos\alpha \sin\alpha \right)}$$

时, 产生调制不稳定性.

对于反常色散区, 产生增益谱的频率区域满足 (12a) 和 (12b) 式, 对应的增益为 (12c) 式. 图 1 为在反常色散区输入临界功率与偏振方向夹角的关系, 在中心区域产生调制不稳定性所需的输入功率最小.

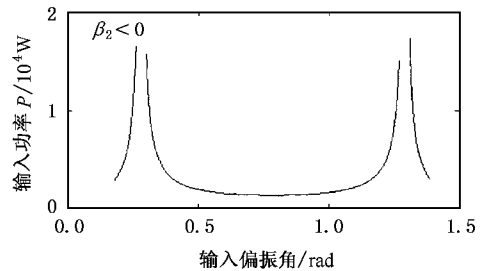


图 1 输入临界功率与偏振方向夹角的关系

图 2 为在偏振角一定时 ( $\alpha = \pi/3$ ), 反常色散区当输入不同功率时调制不稳定性增益. 从图 2 可以看出, 随输入功率的增大, 增益谱增强, 并且远离原始频率  $\omega_0$ . 图 3 为输入功率一定时 ( $P = 600\text{W}$ ), 不同偏振方向 ( $0.27895\text{rad} < \alpha < 1.29185\text{rad}$ ) 时, 增益谱与偏振角  $\alpha$  的关系. 从图 3 可以看出, 当  $0.27895\text{rad} < \alpha < \pi/4 \text{rad}$  时, 增益谱随偏振角  $\alpha$  的增大而增强 (12) 式对偏振角  $\alpha$  的关系中, 由于对称性,  $\sin\alpha$  和  $\cos\alpha$  互为余角, 所以当  $\pi/4 \text{rad} \leq \alpha < 1.29185\text{rad}$  时, 增益谱随偏振角  $\alpha$  的增大而减弱, 其减弱的趋势与  $0.27895\text{rad} < \alpha \leq \pi/4 \text{rad}$  时增强的趋势相同. 图 4 为输入功率一定时 ( $P = 6000\text{W}$ ), 不同偏振方向  $0.18417\text{rad} \leq \alpha < 0.27895\text{rad}$  时, 增益谱与偏振角  $\alpha$  的关系. 可以看出, 当  $0.18417\text{rad} \leq \alpha < 0.27895\text{rad}$  时, 增益谱随偏振角  $\alpha$  的减小而增强. 从

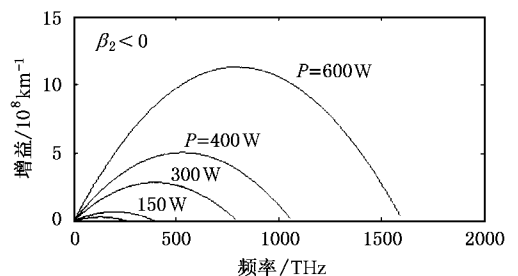


图 2 P 取不同值时调制不稳定性增益

图1可以看出,在  $0.18417\text{rad} \leq \alpha < 0.27895\text{rad}$  区域,输入临界功率随偏振角  $\alpha$  的减小而减小.同样在  $1.29185\text{rad} < \alpha \leq 1.38662\text{rad}$  区域,增益谱随偏振角  $\alpha$  的增大而增强.在  $0.18417\text{rad} \leq \alpha < 0.27895\text{rad}$  或  $1.29185\text{rad} < \alpha \leq 1.38662\text{rad}$  区域,同样在偏振角一定时,增益谱随输入功率的增大而增强.

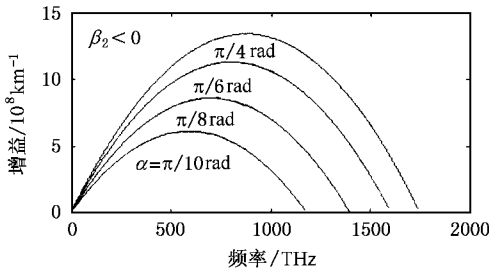


图3  $P = 600\text{W}$ ,  $\alpha$  取不同值时调制不稳定性增益( $0.27895\text{rad} \leq \alpha \leq 1.29185\text{rad}$ )

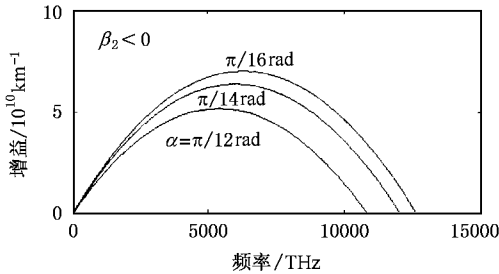


图4  $P = 6000\text{W}$ ,  $\alpha$  取不同值时调制不稳定性增益( $0.18417\text{rad} \leq \alpha \leq 0.27895\text{rad}$ )

### 2.2. 正常色散区

对于正常色散区  $\text{sgr}(\beta_2) = 1$  则

$$\Omega_+^2 = \frac{\delta^2}{\beta_2^2} - \frac{2\gamma P(\cos\alpha + \sin\alpha)}{|\beta_2|} + \frac{1}{2} \left\{ \frac{25 \times 32}{9} \frac{\gamma^2}{\beta_2^2} P^2 \cos\alpha \sin\alpha - \frac{16\gamma^2}{\beta_2^2} P^2 \right\}^{1/2}, \quad (14a)$$

$$\Omega_-^2 = \frac{\delta^2}{\beta_2^2} - \frac{2\gamma P(\cos\alpha + \sin\alpha)}{|\beta_2|} - \frac{1}{2} \left\{ \frac{25 \times 32}{9} \frac{\gamma^2}{\beta_2^2} P^2 \cos\alpha \sin\alpha - \frac{16\gamma^2}{\beta_2^2} P^2 \right\}^{1/2}. \quad (14b)$$

对应的增益为

$$g_-(\Omega) = \mathcal{I} \{ I_m(K) \}$$

$$= \frac{1}{2} \beta_2^2 \Omega_+^4 + \beta_2 \Omega_+^2 \gamma P (\cos\alpha + \sin\alpha) + \frac{1}{2} \Omega_+^2 \delta^2 - \left[ \frac{34}{9} \beta_2^2 \Omega_+^4 \gamma^2 P^2 \cos\alpha \sin\alpha - \beta_2^2 \Omega_+^4 \gamma^2 P^2 + \frac{1}{4} \beta_2^2 \delta^2 \Omega_+^6 + \frac{1}{2} \beta_2 \gamma P \delta^2 \Omega_+^4 (\cos\alpha + \sin\alpha) \right]^{1/2}. \quad (15)$$

同样,因为  $\Omega_+^2 \geq 0, \Omega_-^2 \geq 0$ , 所以要求

$$\frac{25 \times 32}{9} \frac{\gamma^2}{\beta_2^2} P^2 \cos\alpha \sin\alpha - \frac{16\gamma^2}{\beta_2^2} P^2 \geq 0,$$

解得  $0.18417\text{rad} \leq \alpha \leq 1.38662\text{rad}$ .

根据调制和增益性质的要求,

$$\frac{34}{9} \beta_2^2 \Omega_+^4 \gamma^2 P^2 \cos\alpha \sin\alpha - \beta_2^2 \Omega_+^4 \gamma^2 P^2 + \frac{1}{4} \beta_2^2 \delta^2 \Omega_+^6 + \frac{1}{2} \beta_2 \gamma P \delta^2 \Omega_+^4 (\cos\alpha + \sin\alpha) \geq 0,$$

解得

$$\Omega_+^2 \geq \left( 1 - \frac{34}{9} \cos\alpha \sin\alpha \right) \frac{4\gamma^2 P^2}{\delta^2} - \frac{2\gamma P}{\beta_2^2} (\cos\alpha + \sin\alpha).$$

因为  $\Omega_+^2 \geq 0$ , 所以要求

$$\left( 1 - \frac{34}{9} \cos\alpha \sin\alpha \right) \frac{4\gamma^2 P^2}{\delta^2} - \frac{2\gamma P}{\beta_2^2} (\cos\alpha + \sin\alpha) \geq 0,$$

解得

$$P \geq \frac{\delta^2 (\cos\alpha + \sin\alpha)}{2\beta_2 \gamma \left( 1 - \frac{34}{9} \cos\alpha \sin\alpha \right)}. \quad (16a)$$

当

$$\left( 1 - \frac{34}{9} \cos\alpha \sin\alpha \right) > 0, \quad (16b)$$

解得  $\alpha < 0.27895\text{rad}$  ( $\alpha < 15.98266^\circ$ ) 或  $\alpha > 1.29185\text{rad}$  ( $\alpha > 74.01734^\circ$ ).

当

$$\left( 1 - \frac{34}{9} \cos\alpha \sin\alpha \right) < 0, \quad (16c)$$

解得

$$P < \frac{\delta^2 (\cos\alpha + \sin\alpha)}{2\beta_2 \gamma \left( \frac{34}{9} \cos\alpha \sin\alpha - 1 \right)}.$$

当  $0.27895\text{rad} < \alpha < 1.29185\text{rad}$ ,

$$0 < P < \frac{\delta^2 (\cos\alpha + \sin\alpha)}{2\beta_2 \gamma \left( \frac{34}{9} \cos\alpha \sin\alpha - 1 \right)}$$

时,产生调制不稳定性.当  $\alpha = 0.27895\text{rad}$  或  $\alpha = 1.29185\text{rad}$  时,  $\left( \frac{34}{9} \cos\alpha \sin\alpha - 1 \right) = 0$ , 此时对于输入任何功率 (16a) 式都不满足.所以当  $\alpha = 0.27895\text{rad}$  或  $\alpha = 1.29185\text{rad}$  时,不产生调制不稳定性,并且与

光纤的固有双折射  $\delta$ 、群速度色散  $\beta_2$  和非线性系数  $\gamma$  无关. 当  $0.18417\text{rad} \leq \alpha < 0.27895\text{rad}$  或  $1.29185\text{rad} < \alpha \leq 1.38662\text{rad}$ ,

$$P > \frac{\delta^2(\cos\alpha + \sin\alpha)}{2\beta_2\gamma\left(1 - \frac{34}{9}\cos\alpha\sin\alpha\right)}$$

时, 产生调制不稳定性.

总结上述结果, 在正常色散区输入临界功率与偏振方向夹角的关系, 与反常色散区输入临界功率与偏振方向夹角的关系相同, 如图 1 所示.

图 5 为在偏振角一定时 ( $\alpha = \pi/3 \text{ rad}$ ) 正常色散区输入不同功率时调制不稳定性增益. 从图 5 可以看出, 随输入功率的增大, 增益谱增强, 并且远离原始频率  $\omega_0$ . 与反常色散区变化情况相同. 在不同的功率区域输入功率一定时, 不同偏振方向, 增益谱与

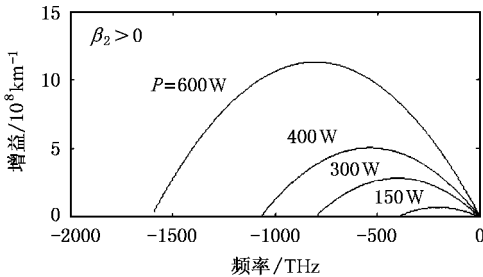


图 5  $P$  取不同值时调制不稳定性增益

偏振角  $\alpha$  的关系与反常色散区定性相同.

### 3. 结 论

当输入光的偏振方向与双折射轴成任意角度时, 在正常色散区和反常色散区产生调制不稳定性的区域和输入临界功率相同, 当  $\alpha = 0.27895$ ,  $1.29185\text{rad}$  和  $0 \leq \alpha < 0.18417$  及  $1.38662\text{rad} < \alpha \leq \pi/2\text{rad}$  时, 不产生调制不稳定性, 可保证激光脉冲的稳定传输.

当  $0.27895\text{rad} < \alpha < 1.29185\text{rad}$ ,

$$0 \leq P \leq \frac{\delta^2(\cos\alpha + \sin\alpha)}{2\beta_2\gamma\left(\frac{34}{9}\cos\alpha\sin\alpha - 1\right)}$$

时, 和当  $0.18417\text{rad} \leq \alpha < 0.27895\text{rad}$  或  $1.29185\text{rad} < \alpha \leq 1.38662\text{rad}$ ,

$$P > \frac{\delta^2(\cos\alpha + \sin\alpha)}{2\beta_2\gamma\left(1 - \frac{34}{9}\cos\alpha\sin\alpha\right)}$$

时, 不论在正常色散区和反常色散区产生调制不稳定性, 并且产生调制不稳定性, 增益谱在偏振角  $\alpha$  一定时, 随输入功率的增大而增强. 输入功率一定时, 在不同的偏振区域, 增益谱随偏振角  $\alpha$  的变化而呈现不同的变化趋势.

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# Vector modulation instability in an arbitrary polarized direction in strong birefringence fibers<sup>\*</sup>

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## Abstract

The coherently coupled nonlinear Schrödinger equation of the propagation of a light pulse in a nonlinear birefringence fiber has been utilized. We have studied modulation instability not only in an anomalous dispersion regime but also in a normal dispersion regime when the angle between the polarized direction and the birefringence axes is arbitrary. The results show that the instability polarized region and stability polarized region exist not only in the anomalous dispersion regime but also in the normal dispersion regime. The input pulses have obviously different gain spectra when the instability polarized region and input different power are different.

**Keywords** : arbitrary polarized direction , vector modulation instability , nonlinear fiber optics , birefringence

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