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单元式偏光分束棱镜分束角和光强分束比

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摘要: 为了研究单元式偏光分束棱镜分束角和光强分束比与棱镜结构的关系, 采用从理论上分析 o光、e光的分束角和光强分束比与光轴取向、棱镜结构角及入射角的关系, 并从实验上测量分束角和光强分束比随入射角变化的方法, 进行了理论分析和实验验证, 取得了分束角和光强分束比随光轴取向、棱镜结构角及入射角的变化关系的数学表达式, 并得到了二者随入射角变化的实验数据。结果表明, 在误差所允许的范围内, 实验所测的光强分束比和分束角随入射角的变化与理论计算是一致的, 且分束角的变化约为入射角的 1/2。

关键词: 物理光学; 偏振光学; 偏光棱镜; 分束角; 分束比
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Splitting angle and light intensity splitting ratio of single-element polarized beam splitting prisms

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Abstract In order to study the splitting angle and light intensity splitting ratio changing with the structure of a single-element polarized beam splitting prism, at first how the o light and e light changing with the orientation of principal axis, the structure angle of the prism and the incident angle was analyzed theoretically. Then how the splitting angle and light intensity splitting ratio changing with different incident angles was measured experimentally. The mathematical expression of the splitting angle and light intensity splitting ratio changing with the orientation of principal axis, the structure angle of prism and the incident angle was deduced, and the experimental data of the splitting angle and light intensity splitting ratio changing with the incident angle were obtained. The results indicate: The tested result is well concordant with the theoretical calculation, and the splitting angle is about 1/2 of the incident angle.

Key words physical optics; polarization optics; polarization prism; splitting angle; splitting ratio

引 言

棱镜式偏光镜是偏光技术, 特别是激光应用技术中最广泛采用的偏光器件[1-9]。目前常采用的偏光棱镜按组合形式, 主要有两大类: 胶合型和空气隙型。前者有较高的透射比和良好的偏光性能, 但抗光损伤阈值较低, 不适于在大功率激光中应用, 后者虽具有很高的抗光损伤阈值, 但空气隙的存在使其反射损失较大, 并产生多次反射和干涉现象[1-2], 应用亦受到一定的限制。单元式结构的偏光棱镜由一块双折射晶体(方解石)构成, 所以其具有较高的抗光损伤阈值, 克服了上述两类棱镜的不足, 是一类在大功率激光应用中较理想的激光分束偏光器件。目前, 国内外常用的单元式偏光镜主要有平行分束偏光镜、双反射偏光分束镜和微角分束镜, 这些棱镜均有生产[3-6], 单元式偏光分束镜与这些棱镜相比, 具有分束角大且可调的优点, 另外, 由于经单元式偏光分束镜出射的两束光中, 有一束不变向, 所以, 该偏光棱镜也可以用作检偏镜使用。作者从理论上阐述了单元式偏光分束棱镜分束角和光强分束比随入射角的变化, 并进行了实验验证, 以给相应的应用研究提供参考。

1 单元式偏光分束棱镜结构原理

1.1 分束角

单元式偏光棱镜的原理结构如图 1所示, 构成它的双折射晶体, 主截面垂直于通光端面, 并呈等腰梯形结构。晶体光轴与棱镜反射底面 BC 夹角为 θ, 通光面 AB, CD 与 BC 面夹角为 β。入射光束由入射端面 AB

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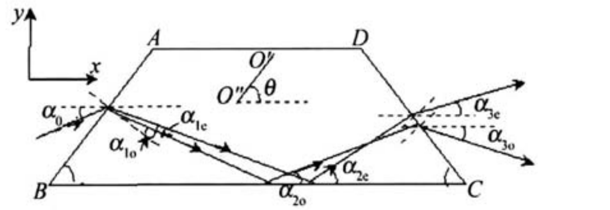

Fig 1 Structure of single-element beam splitting polarization prism

进入棱镜后,由于晶体的双折射效应而分为 o光和 e光;此两光束在底面 BC 上全反射,并进一步分离;最后经 CD 面沿不同方向出射,从而实现起偏、分束。

以 α_{ie}(i= 1, 2, 3)分别代表 e光波在 AB, BC和 CD 界面处折射或反射光光波法线与 x 轴的夹角; α_{io}(i= 1, 2, 3)代表 o光波法线的相应角度; α_0 代表入射光波法线与 x 轴的夹角。同时约定上述角度的正负取值符合:由 x 轴按小于 180°转向光波法线,顺时针为负,逆时针为正。

按照上述约定, o光在 AB, BC 和 CD 界面处满足的折射或反射定律为[10-11]:

$$\begin{cases} \sin\left(\dfrac{\pi}{2} - \beta + \alpha_0\right) = -n_{1o}\sin\alpha_{1o} \\ \alpha_{2o} = \dfrac{\pi}{2} - \beta + \alpha_{1o} \\ n_o\sin\left(\dfrac{\pi}{2} - \beta - \alpha_{2o}\right) = \sin\left(\dfrac{\pi}{2} - \beta - \alpha_{3o}\right) \end{cases} \tag{1}$$

易得 $\alpha_{3o} = -\alpha_0$,由此可见, o光经棱镜后的出射方向与入射方向关于 x 轴是对称的。若光束沿水平方向入射,则有 $\alpha_{3o} = 0$,即 o光水平出射。

对于 e光波法线,有[10-11]:

$$\begin{cases} \sin\left(\dfrac{\pi}{2} - \beta + \alpha_0\right) = -n_{1e}\sin\alpha_{1e} \\ n_{1e}\cos\left(\dfrac{\pi}{2} - \beta + \alpha_{1e}\right) = n_{2e}\cos\alpha_{2e} \\ n_e\sin\left(\dfrac{\pi}{2} - \beta - \alpha_{2e}\right) = \sin\left(\dfrac{\pi}{2} - \beta - \alpha_{3e}\right) \end{cases} \tag{2}$$

式中, $n_{1e} = \dfrac{n_o n_e}{\sqrt{n_o^2\sin^2\phi_1 + n_e^2\cos^2\phi_1}}$, $n_{2e} = \dfrac{n_o n_e}{\sqrt{n_o^2\sin^2\phi_2 + n_e^2\cos^2\phi_2}}$,且 $\phi_1 = \theta + \dfrac{\pi}{2} - \beta + \alpha_{1e}$, $\phi_2 = \theta - \alpha_{2e}$。由此可求得 α_{3e},从而确定 e光经棱镜后的出射方向。一般情况下(θ= 0°, 90°除外), $\alpha_{3o} \neq \alpha_{3e}$, o, e两平面偏振光的分离角为: $\Delta\alpha = |\alpha_{3o} - \alpha_{3e}|$。

1.2 光强分束比

设入射光中 o光和 e光光强分量均为 1,则经过棱镜后,透射 o光和 e光的光强为:

$$\begin{cases} I_o = (1 - R_{1o})(1 - R_{3o}) \\ I_e = (1 - R_{1e})(1 - R_{3e}) \end{cases} \tag{3}$$

式中, R_{1o}, R_{3o}分别是光在 AB, CD 界面处的光强反射系数; R_{1e}, R_{3e}分别是光在 AB, CD 界面处的光强反射系数,且满足[11]:

$$\begin{cases} R_{1o} = \dfrac{\sin^2\left(\dfrac{\pi}{2} - \beta + \alpha_0 + \alpha_{1o}\right)}{\sin^2\left(\dfrac{\pi}{2} - \beta + \alpha_0 - \alpha_{1o}\right)}, R_{3o} = \dfrac{\sin^2\left[\left(\dfrac{\pi}{2} - \beta - \alpha_{2o}\right) - \left(\dfrac{\pi}{2} - \beta - \alpha_{3o}\right)\right]}{\sin^2\left[\left(\dfrac{\pi}{2} - \beta - \alpha_{2o}\right) + \left(\dfrac{\pi}{2} - \beta - \alpha_{3o}\right)\right]} \\ R_{1e} = \dfrac{\tan^2\left(\dfrac{\pi}{2} - \beta + \alpha_0 + \alpha_{1e}\right)}{\tan^2\left(\dfrac{\pi}{2} - \beta + \alpha_0 - \alpha_{1e}\right)}, R_{3e} = \dfrac{\tan^2\left[\left(\dfrac{\pi}{2} - \beta - \alpha_{2e}\right) - \left(\dfrac{\pi}{2} - \beta - \alpha_{3e}\right)\right]}{\tan^2\left[\left(\dfrac{\pi}{2} - \beta - \alpha_{2e}\right) + \left(\dfrac{\pi}{2} - \beta - \alpha_{3e}\right)\right]} \end{cases} \tag{4}$$

则光经过棱镜后,光强分束比由下式给出:

$$I_b = I_o / I_e \tag{5}$$

2 测 量

2.1 分束角测量

棱镜分束角的测试是在精度为 0.5″测角仪上进行的,测试光路如图 2所示。样品棱镜放在测角仪的样品台上,样品台可以旋转且可以读出旋转的角度。

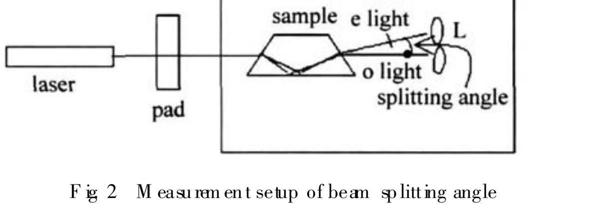

Fig 2 Measurement setup of beam splitting angle

光路中加入衰减器的目的是为了保护眼睛。目镜 L可以随其摆臂绕轴自由转动,对应每一个入射角 α,均用目镜分别对准 o光、e光,目镜转过的角度即是 o光、e光的分束角。测量过程为: (1)将单元式偏光分束棱镜置于光路,调整棱镜,使光平行于棱镜底面入射前端面,即对应图 1中 $\alpha_0 = 0$; (2)旋转测角仪,使 o光、e光分别通过测角仪,读出 2次测角仪的读数,其差即为 o光、e光的分束角; (3)旋转测角仪上的刻度盘,使入射角分别为 α_0 = 1°, 2°, …, 5°, −1°, −2°, …, −5°,测出所对应的分束角。

测量样品取 β = 45°, θ = 45°,入射光波长 λ = 632.8nm,此时 o光的主折射率 n_o = 1.65567, e光的主折射率 n_e = 1.48515,则理论与实验测量到的分束角随入射角的变化如图 3所示。

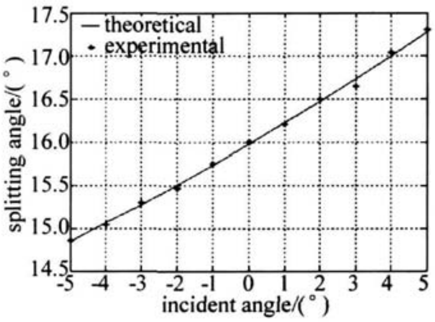

Fig 3　Changeing of beam splitting angle with the incident angle

2.2　光强分束比测量

测试光路如图 4所示。样品棱镜放在测角仪的

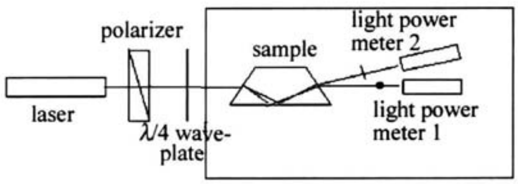

Fig 4　Measurement setup of beam splitting angle

中部, 测角仪角度的读出精度为 15″, 两光功率计是同一型号且由中国计量科学院进行了定标, 加入偏振器和 λ/4波片的目的是为了消除 He-Ne激光器出射光部分偏振对测量的影响。测量过程为: (1)将单元式偏光分束棱镜置于光路, 调整棱镜, 对应图 1中 $\alpha_0=0$; (2)将光探测器的探头分别对准 o光、e光, 同时读出 o光、e光的光强, 求出分束比; (3)旋转测角仪上的刻度盘, 改变入射角, 再测出 o光、e光的光强, 求出分束比。把实验所测的值与理论值相比较, 作出的曲线图见图 5。

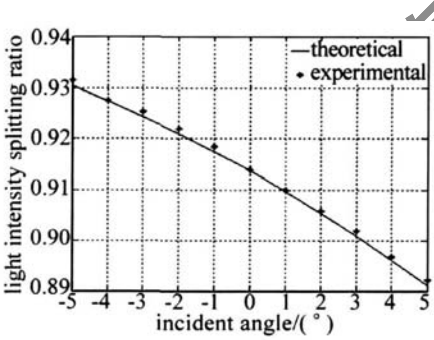

Fig 5　Changeing of beam splitting ratio with the incident angle

3　结　论

(1)单元式偏光分束棱镜的分束角和光强分束比均随入射角的变化而变化。(2)分束角与入射角的关系基本呈线性变化, 且分束角的变化约为入射角的 1/2。(3) o光、e光的光强分束比随入射角在负方向的增大而趋向与 1, 但此时 o光、e光之间的分束角要变小, 所以, 在使用时应综合考虑 o光、e光的分束角及光强分束比, 以选择合适的入射角。

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