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有机无刻痕光栅的研制

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摘要 通过有机合成获得了香蕉形分子化合物 1,3-phenylene bis(4-methoxy-benzylidene amine)。将少量的香蕉形分子化合物夹在两块玻璃衬底之间,加热到 150 °C 使其熔化,然后自然冷却至室温,香蕉形分子可自组装成有机无刻痕光栅。偏光显微镜分析表明,这些香蕉形分子能够在两块玻璃衬底之间通过分子自组装技术而形成平行且等间距、折射率呈周期性变化的条纹。氦氖激光衍射实验表明,香蕉形分子自组装而成的光栅与有刻痕光栅相比同样可对红光进行有效衍射。从香蕉形分子的立体结构出发,探讨了香蕉形分子自组装成有机无刻痕光栅的形成机制,并导出了有机无刻痕光栅的衍射光强分布公式。

关键词 光栅; 香蕉形分子; 自组装; 衍射花样

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Fabrication of Organic Groove-Free Gratings

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Abstract Banana-shaped compound 1,3-phenylene bis(4-methoxy-benzylidene amine) was synthesized. After a tiny amount of the synthesized banana-shaped molecules were sandwiched between two pieces of glass substrates, the molecules were able to assemble themselves into organic groove-free gratings when the banana-shaped compound was cooled in air to room temperature from its melt state at about 150 °C. Polarizing optical microscopic characterization demonstrates that these banana-shaped molecules can assemble themselves into parallel and equidistant stripes between two pieces of glass substrates with a periodic modulation of the refractive index. He-Ne laser diffraction experiment shows that although the gratings are groove-free, the self-organized optical gratings by the banana-shaped molecules exhibit the same diffraction patterns as classically ruled gratings. From the viewpoint of the steric structure of the banana-shaped molecules, the formation mechanism of the self-assembled groove-free gratings was discussed and the diffraction equation was derived for the self-assembled groove-free gratings for the organic groove-free gratings.

Key words gratings; banana-shaped molecules; self-assembly; diffraction pattern

1 引 言

光栅在现代科技中有着重要的地位,广泛地应用于各种光谱仪、天文望远镜、液晶材料的取向排列等领域^[1],而研制各种所需要的光栅就成了光栅研究领域的重要一环。一般而言,制作光栅需要全息离子束刻蚀机、光栅刻划机等一系列复杂而昂贵的专用设备,从而造成了光栅的制作成本居高不下。为增强国产光栅及其光谱仪器在国际上的竞争力,

研发出低成本、高质量的新型国产光栅将是一条重要途径。利用香蕉形分子的自组装特性,我们成功研制出一种无刻痕的有机光栅。通过有机合成,获得了香蕉形分子化合物 1,3-phenylene bis(4-methoxy-benzylidene amine)。将少量的香蕉形分子化合物夹在两块玻璃衬底之间,加热到 150 °C 使其熔化,然后自然冷却至室温,香蕉形分子便可自组装成有机无刻痕光栅,其光栅常数为 83 lines/mm。

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2 实 验

实验合成了香蕉形分子化合物。有机合成所需的化学试剂间苯二胺、对甲氧基苯甲醛、催化剂乙酸购自 Alfa Aesar(均为分析纯)。经提纯后的目标产物经过红外、紫外、核磁共振分析,确认其化学结构如图 1 所示。取少量合成的香蕉形化合物,夹在两块玻璃衬底之间,加热到 $150\text{ }^{\circ}\text{C}$ 使其熔化,然后自然冷却至室温,香蕉形分子便可自组装成有机无刻痕光栅。

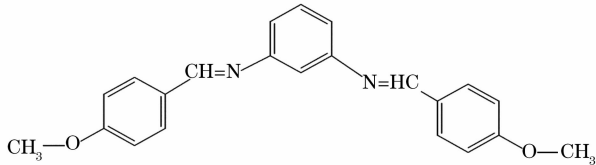


图 1 合成的香蕉形化合物的分子结构

Fig. 1 Molecular structure of the synthesized banana-shaped compound

3 结果与讨论

图 2 的偏光显微镜分析结果表明,这些香蕉形分子可在两块玻璃衬底之间通过分子自组装而形成平行且等间距、折射率呈周期性变化的条纹。随着光栅形成的物理条件不同,条纹间距在 $12\sim 22\text{ }\mu\text{m}$ 之间可调,即形成光栅的光栅常数在 $45\sim 83\text{ line/mm}$ 之间可调。

氦氛激光衍射实验表明,尽管无刻痕,这些由香蕉形分子自组装而成的光栅能够像有刻痕光栅那样对红光进行有效衍射。图 3 为香蕉形分子自组装成的有机无刻痕光栅对 633 nm 红光的衍射花样照片

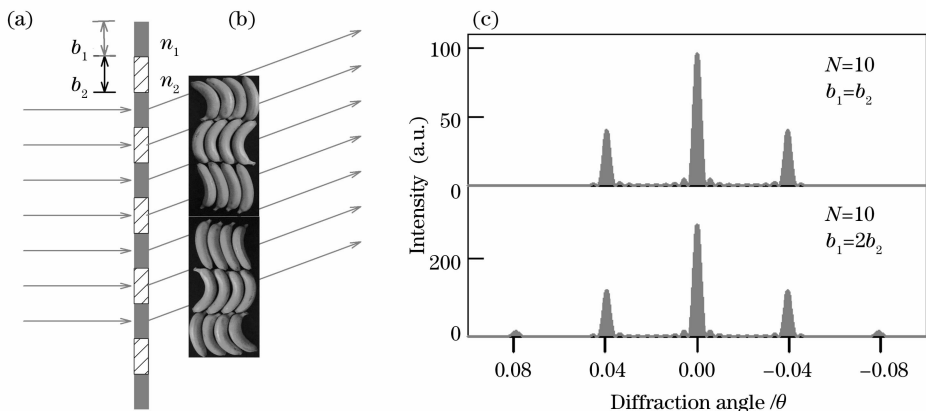


图 4 (a)香蕉形分子能够自组装成无刻痕光栅;(b)香蕉形分子在薄膜中一种可能的最密集排列;(c)计算得到的香蕉形分子自组装光栅的衍射图样

Fig. 4 (a) Schematic illustration of the self-assembled grating with a periodic modulation of refractive indexes n_1 and n_2 ; (b) one of the closed packing of the banana-shaped molecules in the thin films; (c) calculated diffraction patterns for the self-assembled gratings

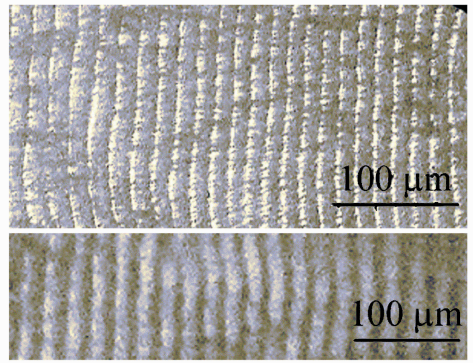


图 2 夹在两块玻璃衬底之间的香蕉形化合物薄膜的偏光显微镜织构图

Fig. 2 Micrographs of the thin films of the synthesized banana-shaped compound sandwiched between two glass substrates by polarized light microscope

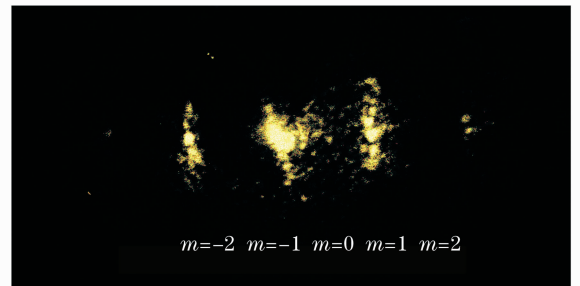


图 3 香蕉形分子自组装成的有机无刻痕光栅对 633 nm 红光的衍射花样照片

Fig. 3 Typical photographs of the diffraction patterns of the self-assembled optical gratings formed by the banana-shaped molecules. The wavelength of the incident light is 633 nm

片。从图中可以清楚地看出光栅的二级衍射花样。

从香蕉形分子的立体结构出发,可以探讨香蕉形分子自组装成有机无刻痕光栅的形成机制。由于香蕉形分子特有的立体结构,在薄膜中它们将采取最密集排列以使所形成的薄膜能量最低。图 4(b)给出了香蕉形分子在薄膜中一种可能的最密集排列。在这种最密集排列中,香蕉形分子可形成层状结构,其厚度在微米量级^[2~7]。显然在相邻的层与层之间,其折射率不同,从而香蕉形分子能够自组装成无刻痕光栅,如图 4(a)所示。

假设香蕉形分子所形成的薄膜厚度为 d ,相邻的层宽度分别为 b_1 和 b_2 ,相应地其折射率分别为 n_1 和 n_2 。令参数

$$\phi_1 = 2\pi b_1 \sin \theta / \lambda, \quad (1)$$

$$\phi_2 = 2\pi b_2 \sin \theta / \lambda, \quad (2)$$

$$\delta n = n_2 - n_1, \quad (3)$$

$$p = b_1 + b_2, \quad (4)$$

其中 θ 为衍射角, λ 为入射光波长。根据光学原理,可导出有机无刻痕光栅的衍射光强分布公式为

$$I = I_0 \left[\frac{\sin(N\pi p \sin \theta / \lambda)}{\sin(\pi p \sin \theta / \lambda)} \right]^2 \times \left\{ \left[\frac{\sin(\phi_1/2)}{\phi_1/2} \right]^2 + \left[\frac{\sin(\phi_2/2)}{\phi_2/2} \right]^2 + 2 \frac{b_2}{b_1} \left[\frac{\sin(\phi_1/2)}{\phi_1/2} \right] \left[\frac{\sin(\phi_2/2)}{\phi_2/2} \right] \cos \left(\frac{2\pi d \delta n}{\lambda} \right) \right\}, \quad (5)$$

其中 N 为光栅的条数。根据(5)式,令 $N=10$ 及 $p=16 \mu\text{m}$,可计算出香蕉形分子自组装光栅的衍射图样,结果如图 4(c)所示。由图可知,理论计算所得的衍射图样与自组装光栅的实验衍射图样相当吻合。因此,同其他光栅一样^[8~10],这些无刻痕光栅在现代科技中将有着重要用途。

4 结 论

采用有机合成的香蕉形分子化合物 1, 3-phenylene bis(4-methoxy-benzylidene amine) 能够自组装成有机无刻痕光栅。这些香蕉形分子在两块玻璃衬底之间通过分子自组装技术而形成平行且等间距、折射率呈周期性变化的层状结构,并能对红光进行有效衍射。这种无刻痕的有机光栅不仅制造成本低,而且可在两块玻璃衬底之间封装,从而使其可以耐磨、耐擦伤、防潮防尘。

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