

一种测量非均匀固体混合物的折射率和比例的方法

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Nan Kai University.



目录

- 研究背景及研究现状
- 研究方法及模型验证
- 实验结果及分析
- 总结及展望



研究背景及现状



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自然界



生物医学领域



食品行业

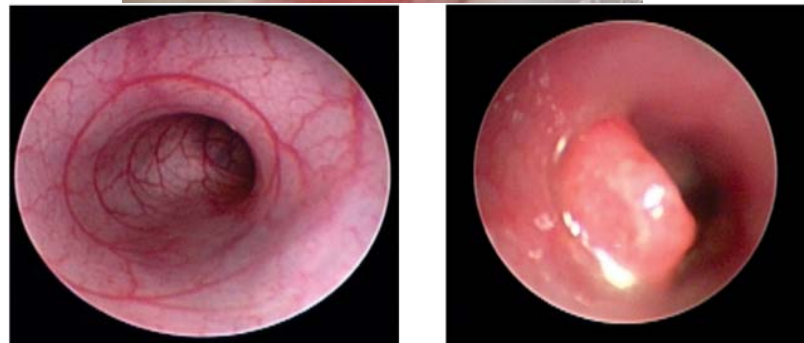


光通信领域



← 自然界

生物相关



当今应用需求：

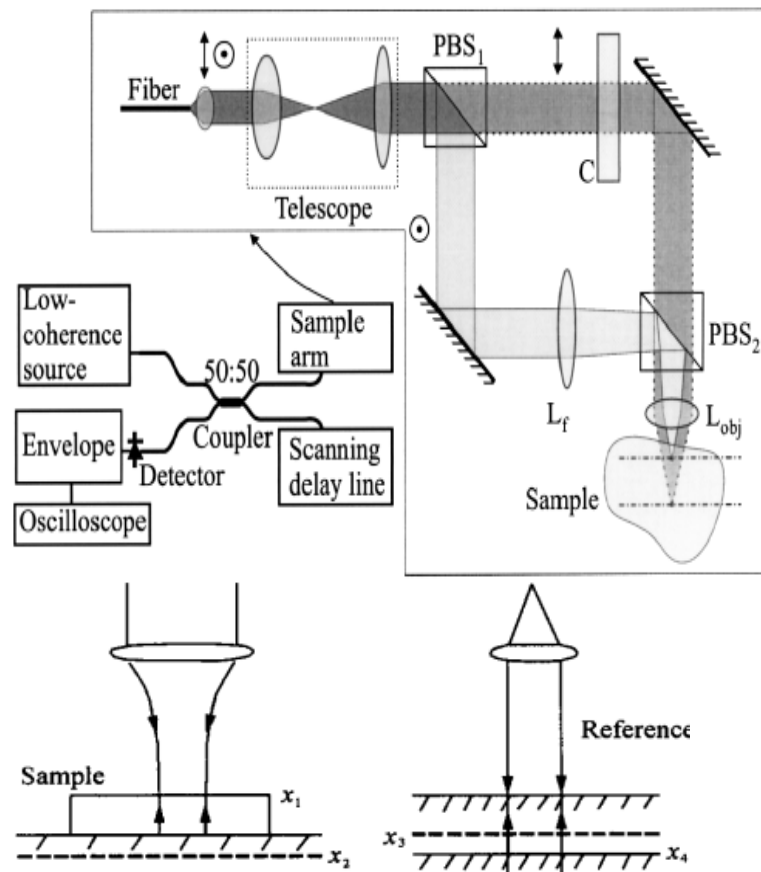
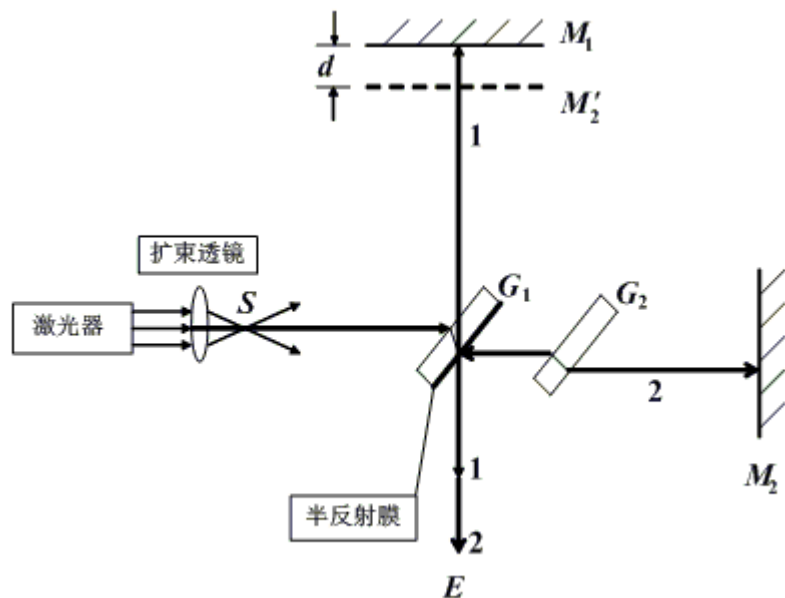
- ▶ 矿物识别
- ▶ 食品分类
- ▶ 高灵敏生物传感
- ▶ 激光治疗
- ▶

- 干涉法, OCT法 (Optical Coherence Tomography);
- 最小偏向角法 (Minimum deviation angle method);
- 椭圆偏振法 (Ellipsometry);
- 表面等离子体共振法 (Surface plasmon resonance, SPR);
- 相差显微法 (Phase-contrast microscopy);
- 光纤包层填充法 (Fiber cladding method);
- 激光束法 (Laser beam method);
- 液浸法 (Liquid immersion method);
- *全内反射法 (Total internal reflection, TIR);*



迈克尔逊干涉仪和OCT法

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- F. Bolin, et.al, *Appl. Opt.* 28(12), 2297-2303 (1989).
- S. a Alexandrov, et.al, *Optics letters* 28, 117-9 (2003).
- X. Wang, et.al, October 7, 628-632 (2002).

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最小偏向角法和椭圆偏振法

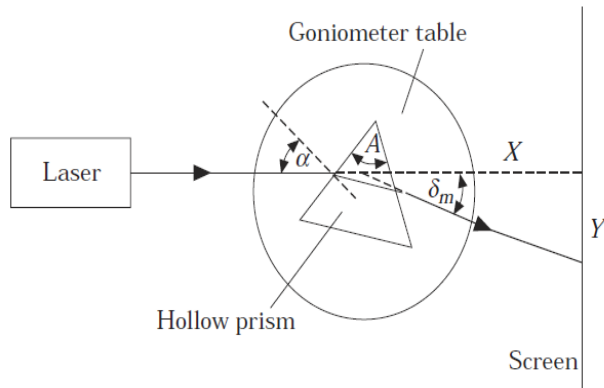


Fig. 1. Schematic of the experimental setup for the measurement of index of refraction.

$$n = \frac{\sin\left(\frac{A + \delta_m}{2}\right)}{\sin\left(\frac{A}{2}\right)}$$

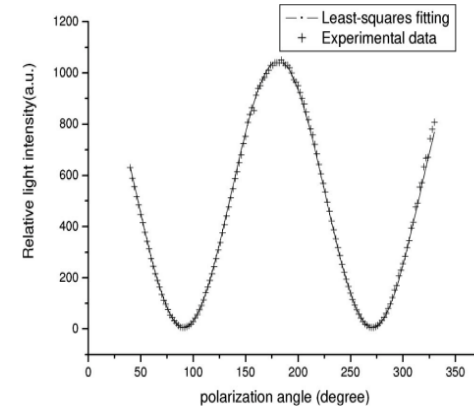
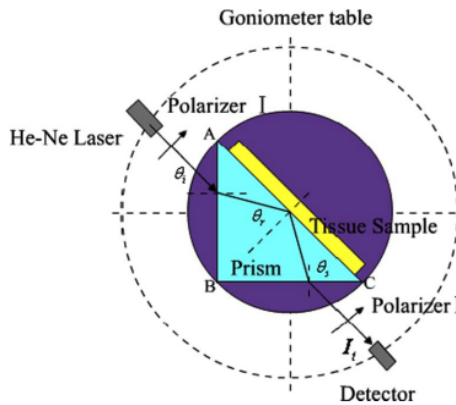


Table 1. Complex Refractive Indices of Measured Samples under Wavelength of 632.8 nm

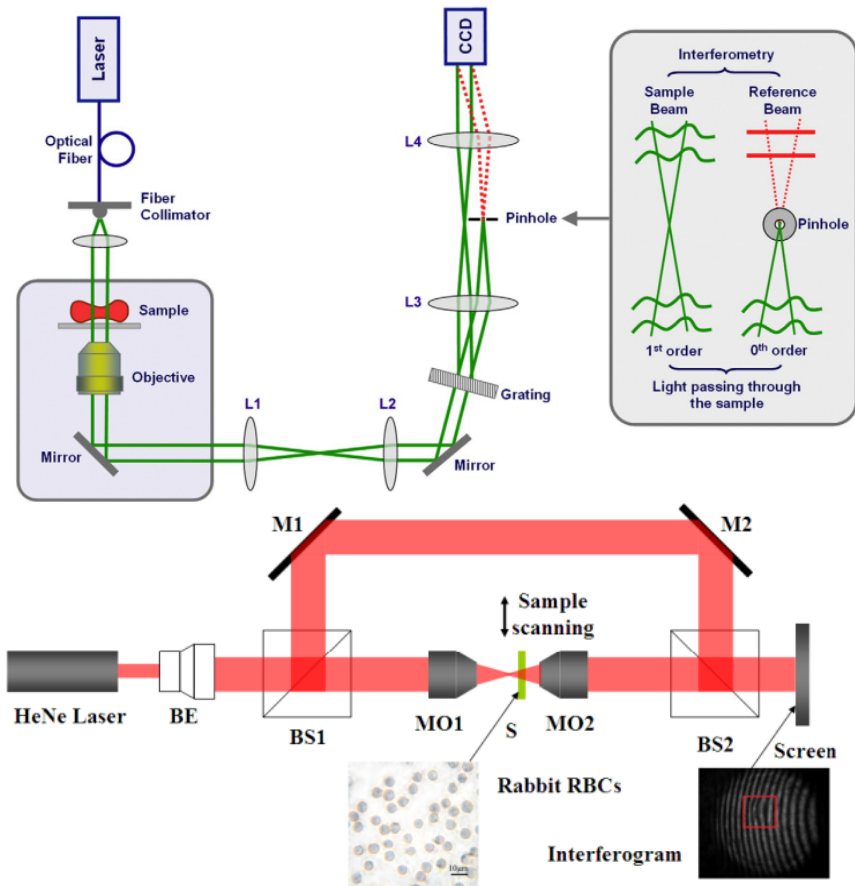
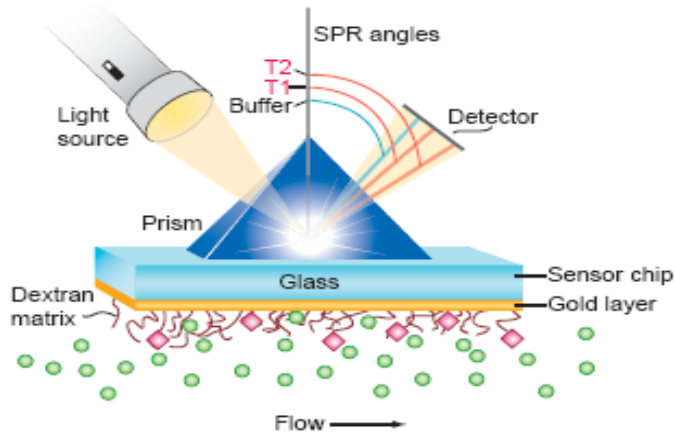
Samples	n
Muscle tissue	$1.3713 + 0.0062i$
Liver tissue	$1.3791 + 0.0087i$
Pancreas tissue	$1.3517 + 0.0113i$
Dermis tissue	$1.3818 + 0.0049i$

- D. K. Sardar and L.B. Levy, "Optical Properties of Whole Blood," *Lasers. Med. Sci.* 13,106–111 (1998).
- J.-C. Lai, Y.-Y. Zhang, Z.-H. Li, H.-J. Jiang, and A.-Z. He, *Applied optics* 49, 3235-8 (2010).



表面等离子体共振法和相差显微法

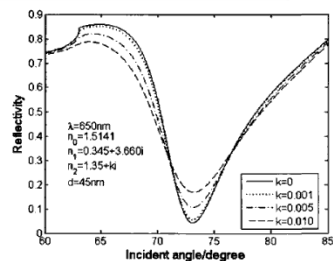
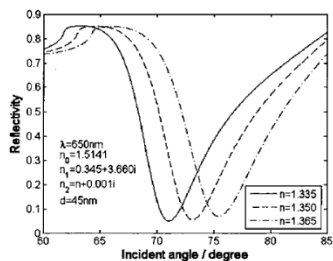
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J. Jääskeläinen, K. E. Peiponen, and J. a Rätty, *Journal of dairy science* 84, 38-43 (2001).

G. Popescu et al. *Blood Cells, Molecules, and Diseases* 41 10–16 (2008)

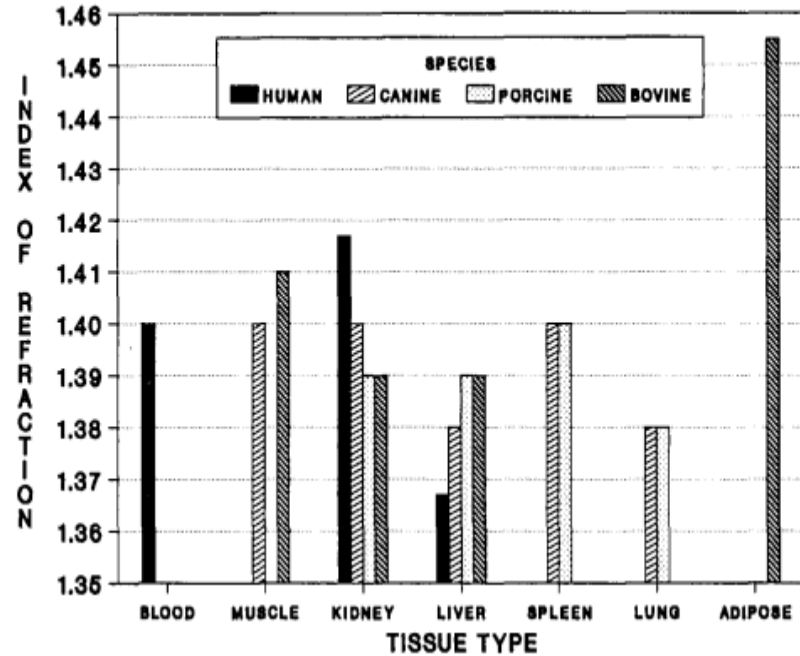
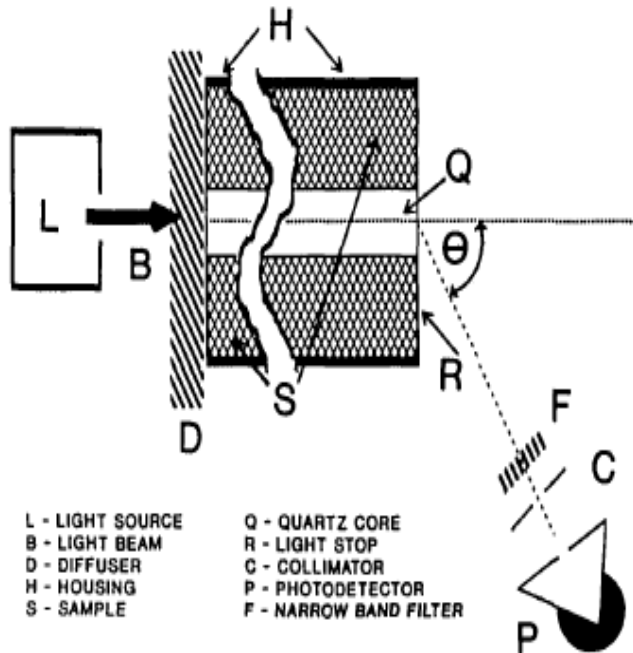
S. Wang, L. Xue, J. Lai, and Z. Li, *Journal of Optics* 14, 065301 (2012).



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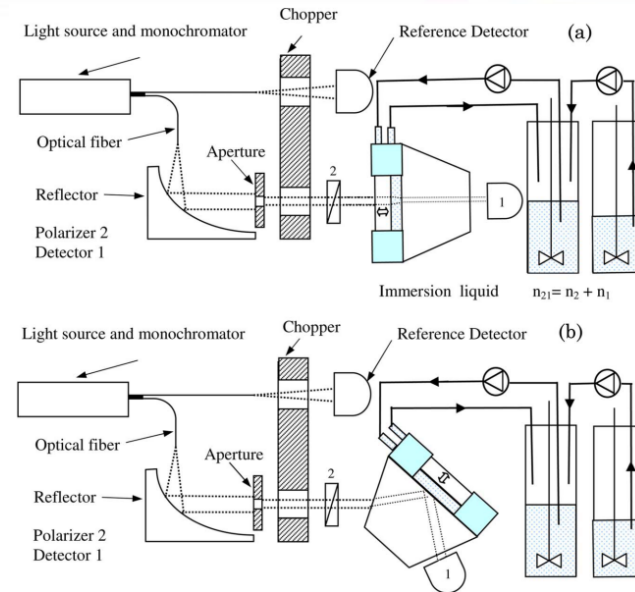
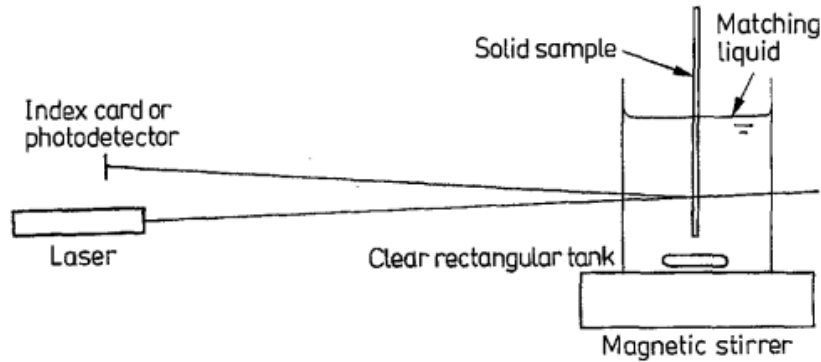
光纤包层填充法



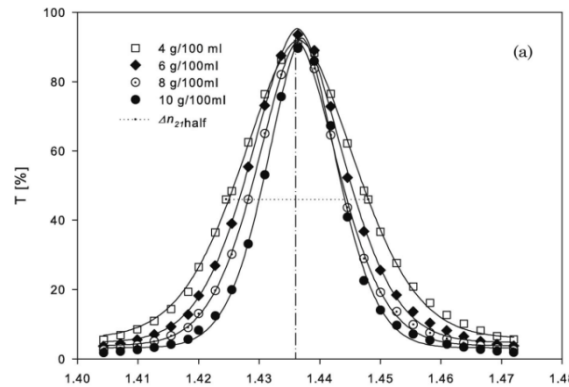
F. Bolin, L.E. Preuss, R. C. Taylor and R. J. Ference, *Appl. Opt.* 28(12), 2297-2303 (1989). [Cited by 311](#)



激光束法和液浸法



- R. Budwig, Exp. Fluids., 17, 350 (1994).

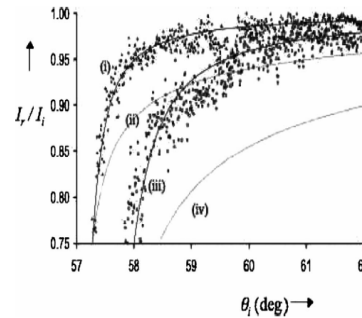
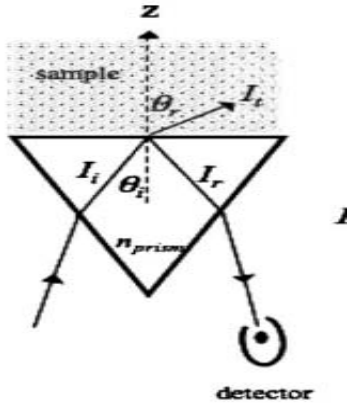
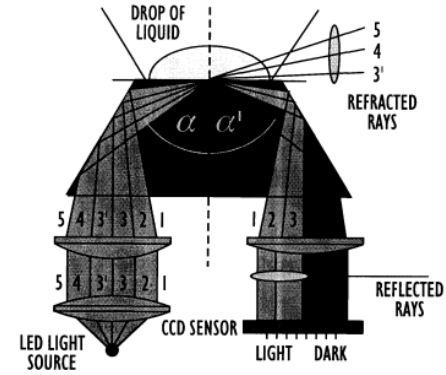
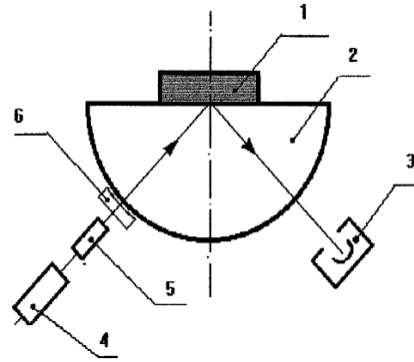
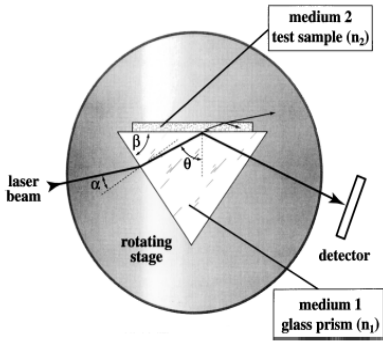


对于两种固体的颗粒混合物（15 μ m直径，97%的均匀度），粒子的直径和一种粒子的折射率信息时，可以使用LIM测量，需要透射光的半波宽信息。

Niskanen I, Rätty J, Peiponen K-erik.. Appl. Opt., 2010, 49: 3428-3433.

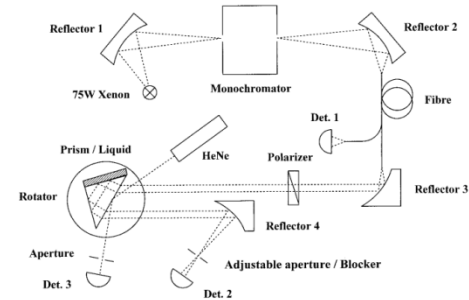


全内反射法



$$n_i(\theta) = n_i(4\pi n_{\text{prism}} \sqrt{(M-L)/2})^{-1}$$

$$R_s^+ = R_s + \varphi R_s^{1.5}(1 - R_s)$$



Chunping Zhang, Q. Wang Song et al. Optics Letters, 1994, 19(18):1409-1411.
 H. Li and S.S. Xie, Appl. Opt. 35(10), 1793-1795 (1996).
 M. Mohammadi, Advances in Colloid and Interface Science 62, 17-29 (1995).
 W. R. Calhoun, H. Maeta, et al. Optics Letters, 2010, 35(8):1224-1226.
 Ilpo Niskanen and Jukka Rätty, Kai-Erik Peiponen. Optics Letters, 2007, 32(7):862-864.



难点：

- 对非均匀固体混合物的分离
- 样品厚度要求
- 样品的表面加工
- 样品内部的散射
- 测量精度



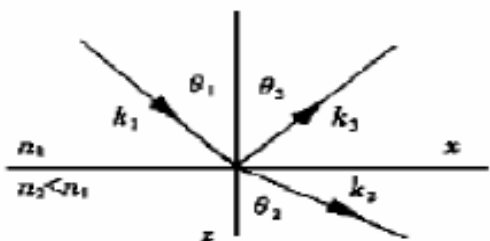
➤ 研究方法以及模型验证



全内反射法

- 当光从光密介质入射到光疏介质时 ($n_1 > n_2$) 就会有全反射现象的产生。

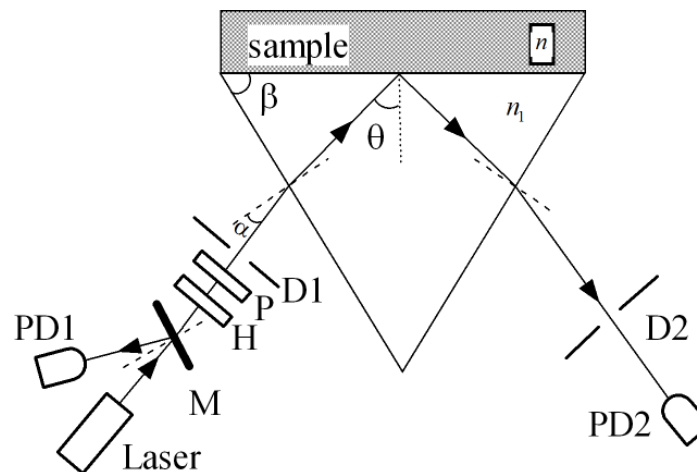
$$n_1 \sin \theta_1 = n_2 \sin \theta_2$$



界面



界面



光路: Laser-632.8nm激光器, PD1/PD2—光电探测器; M—半透半反镜; H—1/2波片; P—偏振片; D1/D2—光阑;



$$E = E_0 e^{-\mu z/2} e^{i(kz - \omega t)}$$

$$E = E_0 e^{i2\pi z/\lambda n}$$

$$\kappa = \mu_t \lambda / 4\pi \quad \mu_t = \mu_s + \mu_a$$

不同界面上的反射率可以由菲涅耳公式计算：

$$R_{1,2} = \frac{(n_1 \cos \theta - u_2)^2 + v_2^2}{(n_1 \cos \theta + u_2)^2 + v_2^2}$$

$$R_{2,3} = \left(\frac{\cos \alpha - n_1 \cos(\text{asin}(\sin \alpha / n_1))}{\cos \alpha + n_1 \cos(\text{asin}(\sin \alpha / n_1))} \right)^2$$

$$R_s = R_{1,2} * (1 - R_{2,3})^2$$



折射率的实部

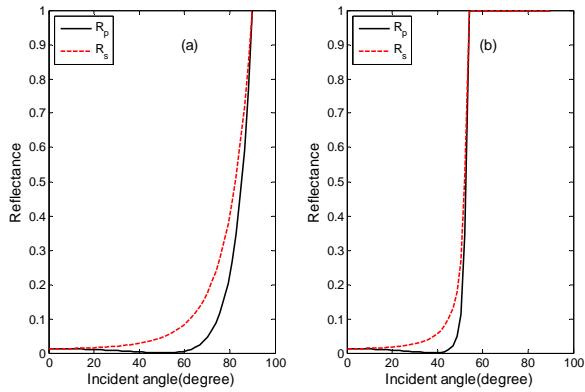
$$\theta_c = \arcsin \frac{n_r}{n_1}$$

$$n_r = n_1 \sin(\beta \pm \arcsin(\sin \alpha / n_1))$$

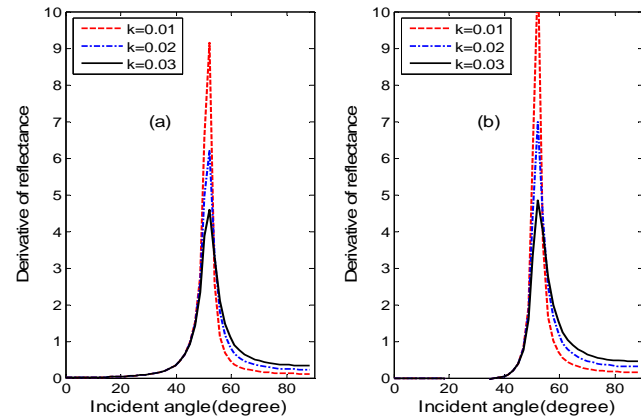
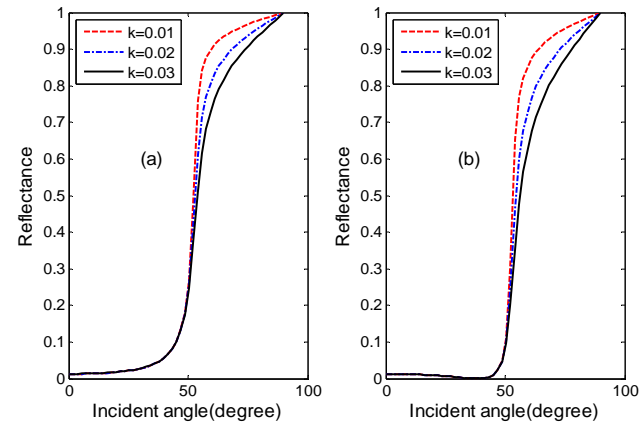
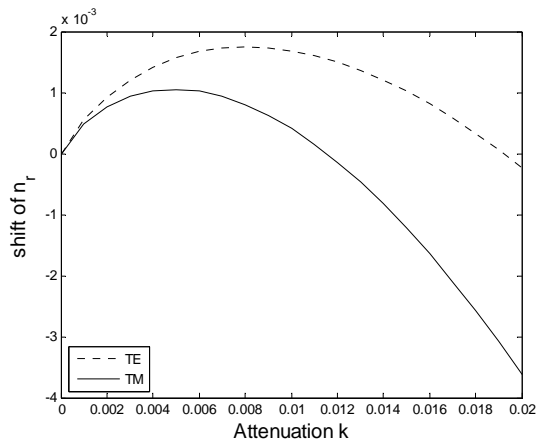
折射率的虚部（消光系数）

$$S(N) = \sum_{i=1}^N [R_{m,i} - R_{s,i}^+]^2$$

$$E_s^2 = 1 - \frac{\sum_{i=1}^N (R_{m,i} - R_{s,i}^+)^2}{\sum_{i=1}^N (R_{m,i} - \bar{R})^2}$$



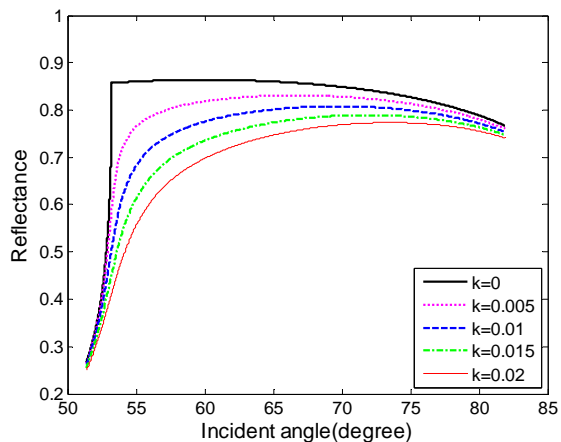
光通过透明介质的反射(a) $n_1=1.37, n_2=1.72$; (b) $n_1=1.72, n_2=1.37$



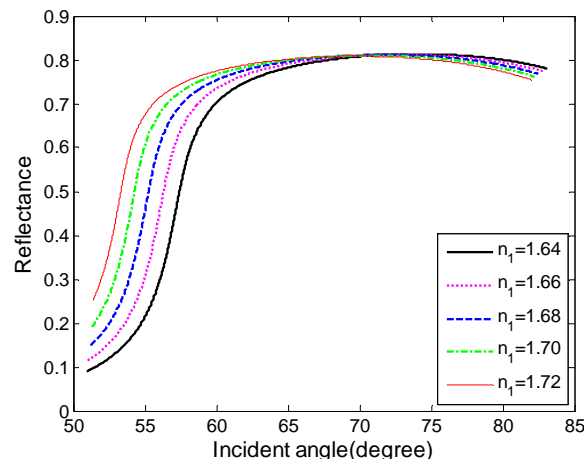
消光系数分别是 $\kappa = 0.01, 0.02, 0.03$

$n_2 = 1.37$

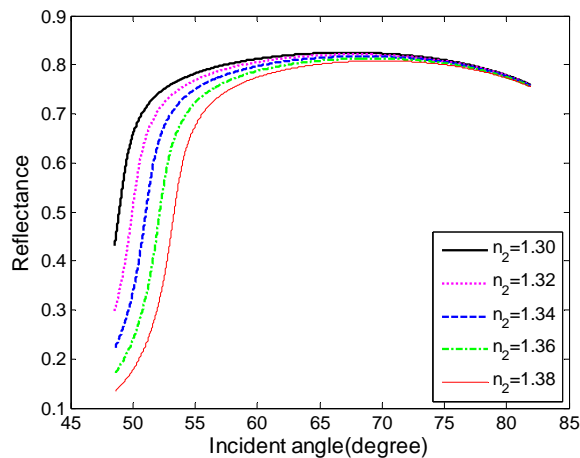




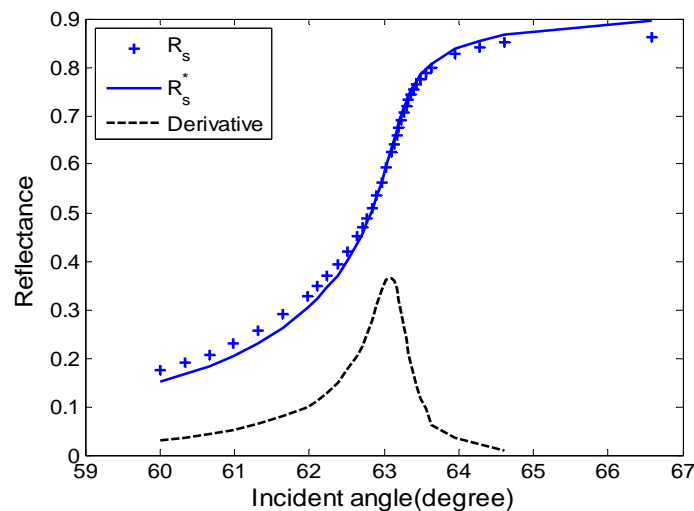
理论计算的不同消光系数的样品在 TE 波入射反射率随入射角度变化的曲线, $n_1=1.723, n_2=1.38$ 。消光系数分别是 $\kappa=0, 0.005, 0.01, 0.015, 0.02$



理论计算的使用不同折射率的棱镜, 样品在 TE 波入射时反射率随入射角度变化的曲线, $n_2=1.38, \kappa_2=0.01$ 。棱镜折射率分别是 $n_1=1.64, 1.66, 1.68, 1.70, 1.72$

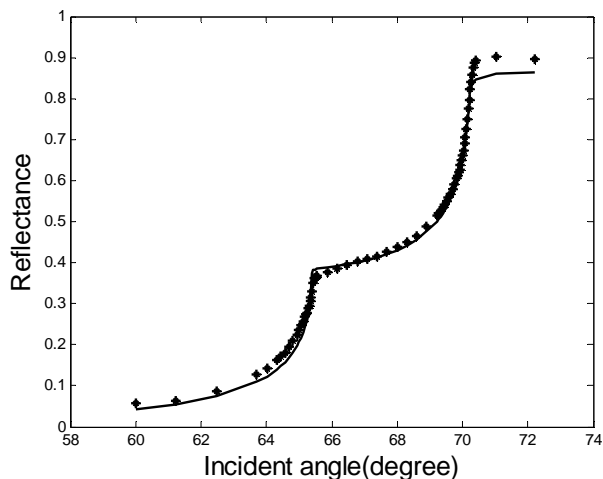


理论计算的使用不同折射率的样品在 TE 波入射时反射率随入射角度变化的曲线, $n_1=1.72, \kappa_1=0.01$ 。样品折射率分别是 $n_2=1.30, 1.32, 1.34, 1.36, 1.38$



TE 波入射时, 印度墨水溶液和 20%的 Introlipid 溶液以 1:1 的比例混合的混合液的反射率数据、拟合曲线和导数曲线。



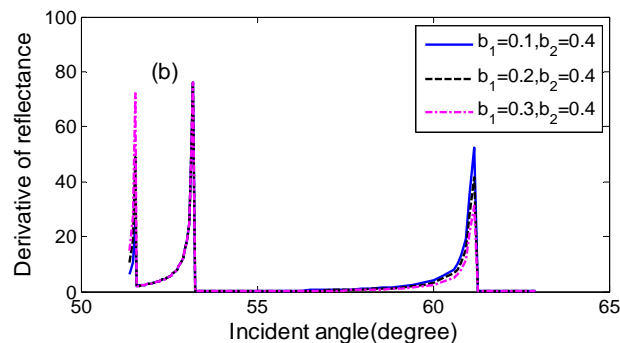
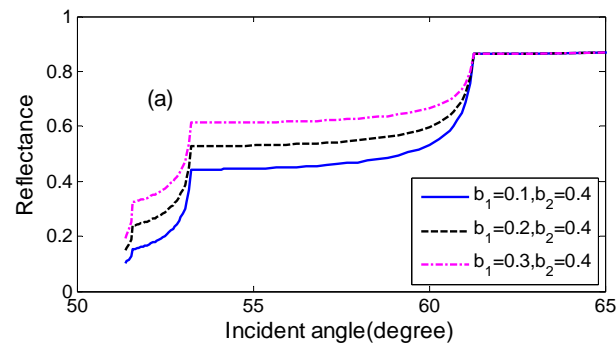


具有两种成分的样品的反射率随入射角度的变化图

$$R_s = \sum_{j=1}^M b_j R_s^j \quad R_p = \sum_{j=1}^M b_j R_p^j$$

$$n_{2,j} = n_1 \sin(\beta \pm \arcsin(\sin \alpha_{c,j} / n_1))$$

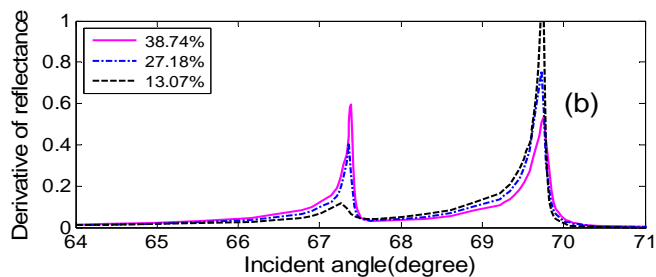
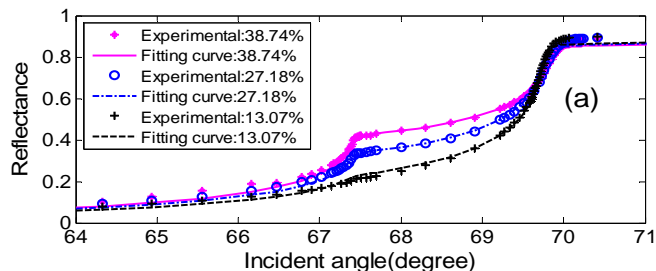
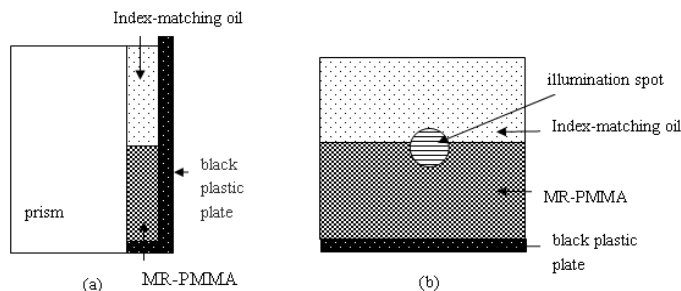
$$S(N) = \sum_{i=1}^N [R_{m,i} - R_{s,i}^+]^2$$



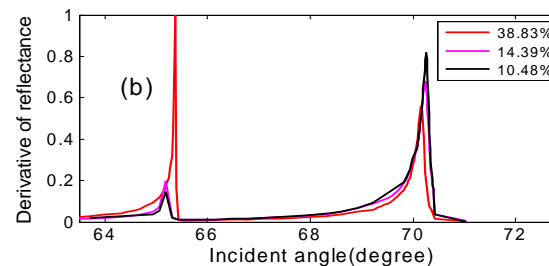
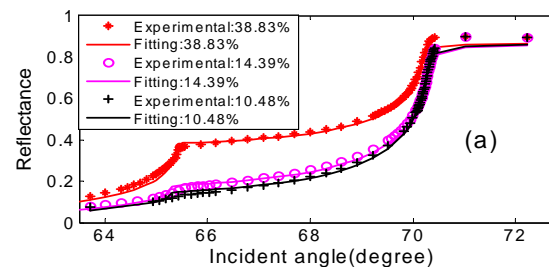
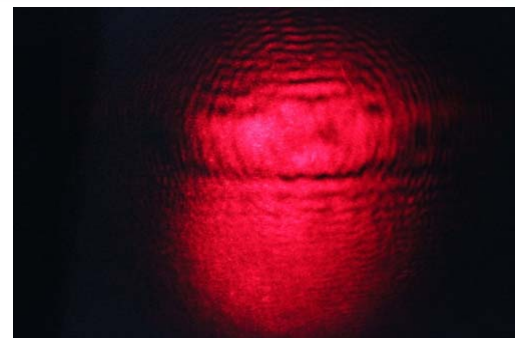
具有相同消光系数不同比例的样品的(a)反射率曲线和(b)导数曲线。



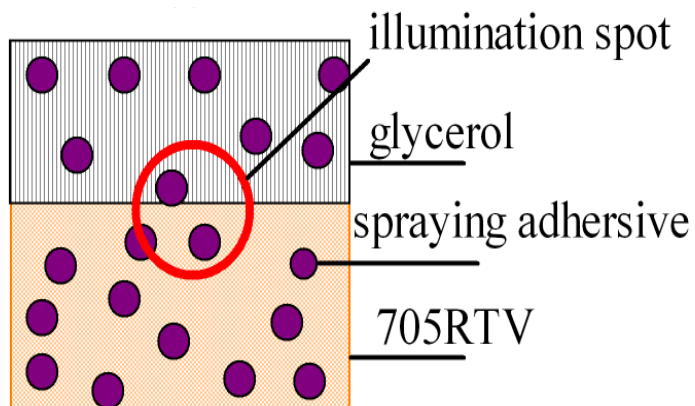
二元模拟样品的制备及模型验证



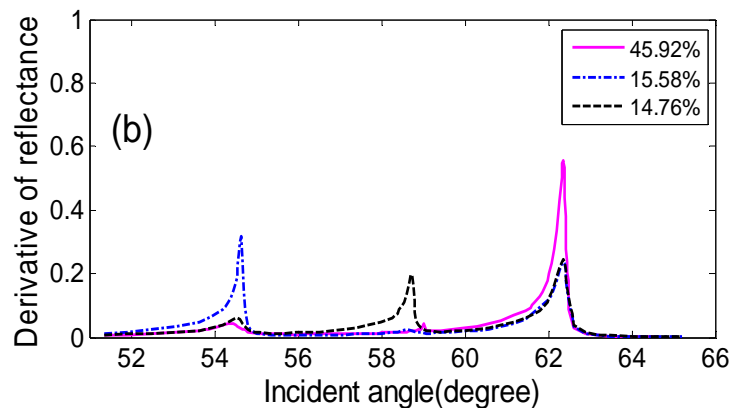
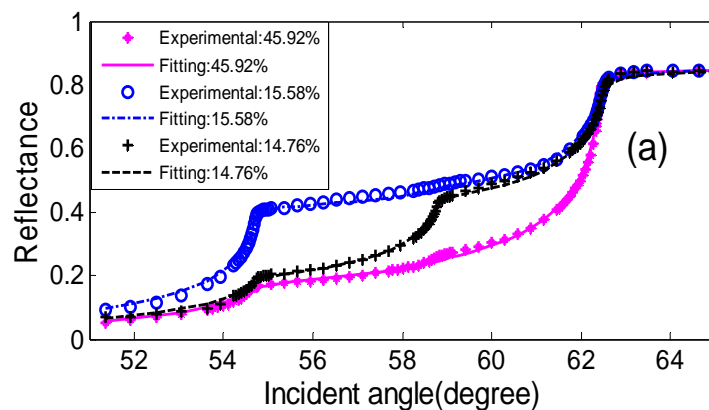
TM光入射时，折射率油和MR-PMMA制作的二元样品的(a) 反射率随角度变化的实验数据和拟合曲线；(b)反射率的导数曲线；



TE光入射时，甘油和MR-PMMA制作的二元样品的(a)随角度变化的反射率实验数据和拟合曲线；(b)反射率的导数曲线；

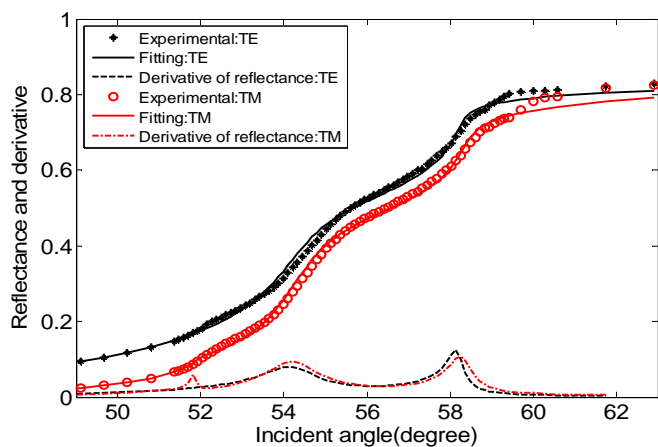


甘油、硅橡胶和喷胶的折射率分别为1.404， 1.471和1.524。

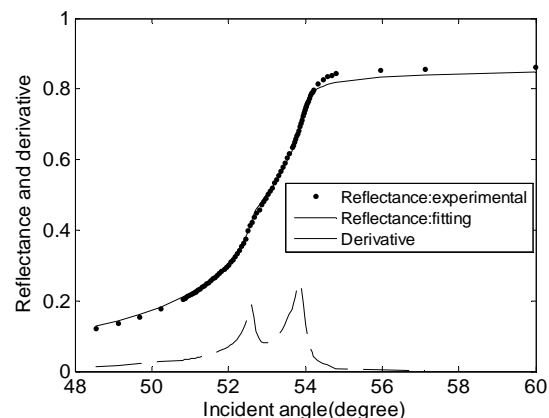


实验结果及讨论

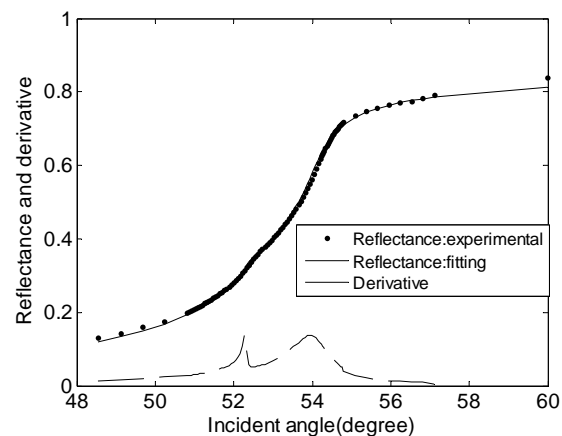




TE和TM光入射时，猪肉组织样品的反射率及导数曲线随入射角度的变化



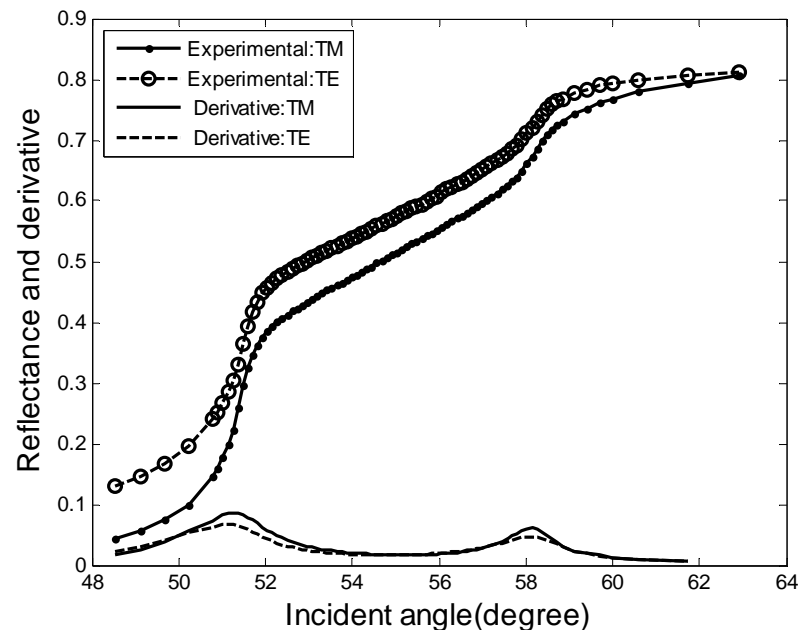
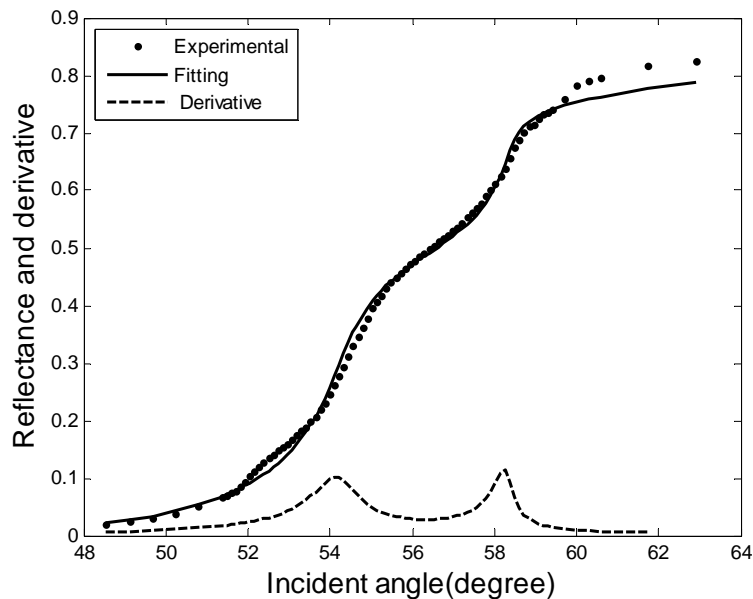
TM光入射时，鸡胸肉组织样品的反射率及导数曲线随入射角度的变化



TM光入射时，羊肉组织样品的反射率及导数曲线随入射角度的变化曲线



讨论1: 两组肥瘦相间的动物组织的测量结果



三个峰计算的对应折射率分别为1.356, 1.340和1.467; 肌肉的比例为61.98%, 脂肪的比例为33.80%, 还有4.22%的组织液。

TM波入射时求出的折射率分别为1.346和1.465, TE波入射时求得的折射率分别是1.346和1.467。这两个值很明显对应于组织液和脂肪组织的折射率。

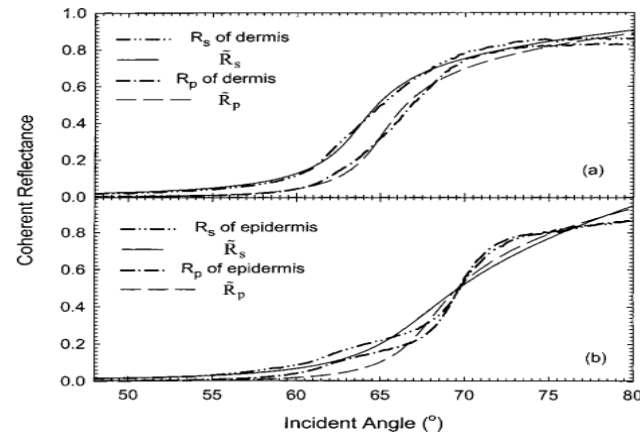
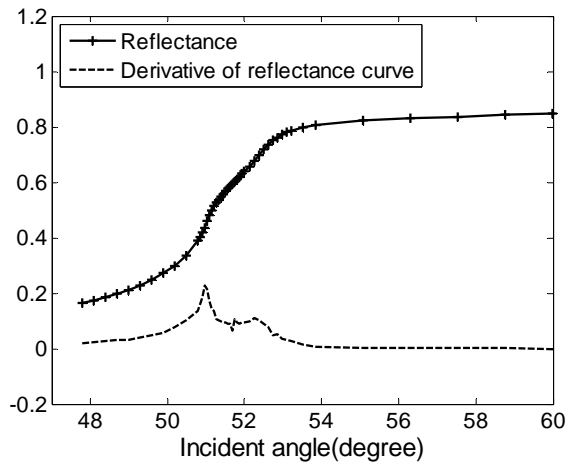


三峰v双峰? 压力效应

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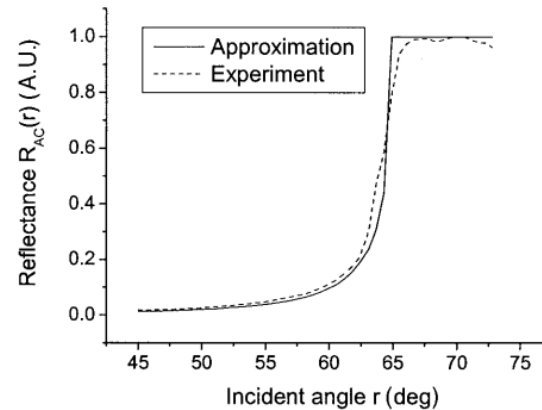


讨论2: 组织液对折射率测量的影响



文献]的图7, 猪的 (a) 真皮和 (b) 表皮组织的反射率随角度的变化测量曲线和拟合曲线。H. Ding, J. Q. Lu, K. M. Jacobs, et al. J. Opt. Soc. Am. A . 2005, 22:1151-1157.

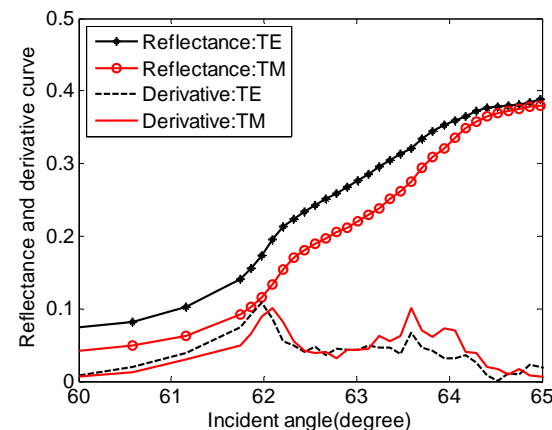
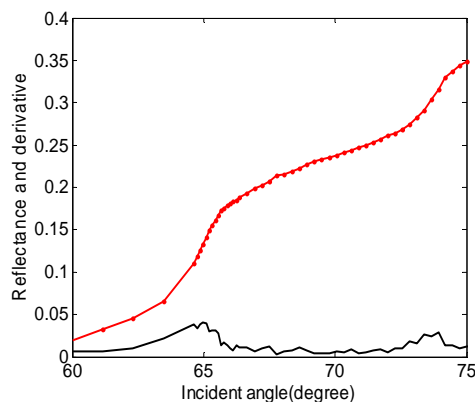
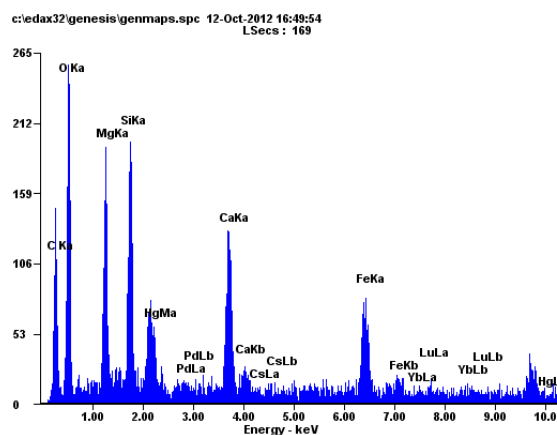
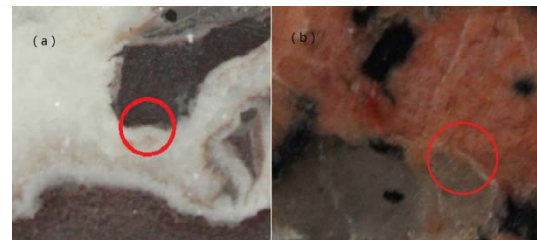
$$R_s^+ = b_1 R_{s1} + b_2 R_{s2}$$



文献的图2, 猪的肾脏组织的反射率随角度的变化测量曲线和拟合曲线。J. Lai, Z. Li, C. Wang, et al.. Appl. Opt., 2005, 44:1845-1849.



矿石样品的测量结果



(a)紫罗红大理石样品, (b)花岗岩样品。圆圈内是照明区域

能谱仪 (Energy Dispersive Spectrometer, EDS)

Table 1 Major element composition measured by EDS

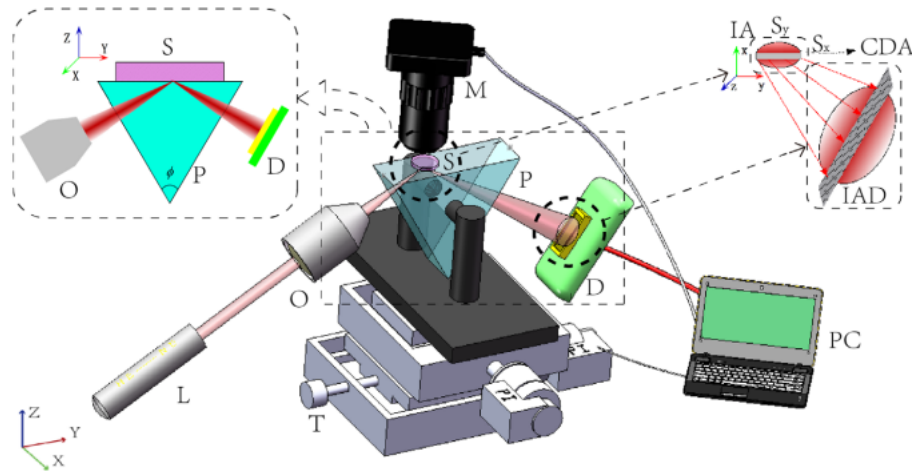
	C	O	Ca	Fe
White area (Weight %)	5.57	34.55	58.89	0
Red-brown area (Weight %)	21.17	29.11	8.18	11.81



总结及展望

优点：克服了液浸法(Liquid immersion method)对固体混合物粒径和分离的要求；

局限：要求被测样品表面具有一定的光学平整度。



致谢

- 感谢南开大学物理学院；
- 感谢大会组委会；
- 感谢所有参加会议的同行。

