Mechanism and physical significance of half-wave loss in reflected light

反射光存在的半波损失现象的机理及其物理意义

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[Abstract] : The fact that the reflected light has half-wave loss proves that the reflected light is not simply reflected from the incident light by the medium interface directly, but has a deep physical mechanism and significance. According to my long-term research, the reflected light is actually a part of the secondary light generated after the incident light makes the atoms on the reflecting interface polarize into electric dipoles. This physical phenomenon reveals the law of interaction between light and medium: the atoms in the medium are converted into electric dipoles by incident photopoles and generate secondary light, and the incident light will be gradually cancelled out and disappear by secondary light in this process. Generally, the refracted light entering the transparent medium and the transmitted light passing through the transparent medium are part of the secondary light produced by the medium, not incident light or its variant.

[文章摘要]：反射光存在半波损失的事实证明：反射光并非是由入射光被介质界面直接反射出来那么简单，而是存在深层次的物理机制和意义。据本人的长期研究发现：反射光实际上是入射光使反射界面上的原子被极化为电偶极子后产生的次生光的一部分。这一物理现象揭示了光与介质相互作用规律是：介质中的原子被入射光极化为电偶极子并产生次生光，入射光在此过程中会被次生光逐渐抵消而消失。通常认为的进入透明介质内部的折射光和穿越透明介质的透射光均是介质产生的次生光的一部分，并非入射光或其变种。

One,A brief introduction to the phenomenon of half wave loss of reflected light

一、反射光存在的半波损失现象简介

When a wave is transmitted from a wave-sparse medium to a wave-dense medium, the vibration direction of the reflected wave when it leaves the reflected point is opposite to that of the incident wave when it arrives at the incident point. In other words, the phase of the reflected wave changes π with respect to the incident wave. This phenomenon is called half-wave loss.

波从波疏介质射向波密介质时反射过程中，反射波在离开反射点时的振动方向相对于入射波到达入射点时的振动相反，或者说反射波相对于入射波相位突变π，这种现象叫做半波损失。

According to wave theory, a wave oscillating in the opposite direction is equivalent to a wave traveling half a wavelength too much (or too little). When the incident light moves forward in the optically sparse medium and meets the interface of the optically dense medium, it generates half wave loss in the reflection process under the two cases of grazing or vertical incidence, which is only for the vibration of the electric field intensity vector of the light. If the incident light moves forward in the optically dense medium, no half-wave loss occurs when it encounters the interface of the optically sparse medium. Regardless of grazing or vertical incidence, the vibration direction of refracted light is relative to the vibration direction of incident light, and no half-wave loss occurs.

从波动理论可知，波的振动方向相反相当于波多走（或少走）了半个波长。入射光在光疏媒质中前进，遇到光密媒质界面时，在掠射或垂直入射 2 种情况下，在反射过程中产生半波损失，这只是对光的电场强度矢量的振动而言。如果入射光在光密媒质中前进，遇到光疏媒质的界面时，不产生半波损失。不论是掠射或垂直入射，折射光的振动方向相对于入射光的振动方向，永远不发生半波损失。

The above is excerpted from the Encyclopedia.

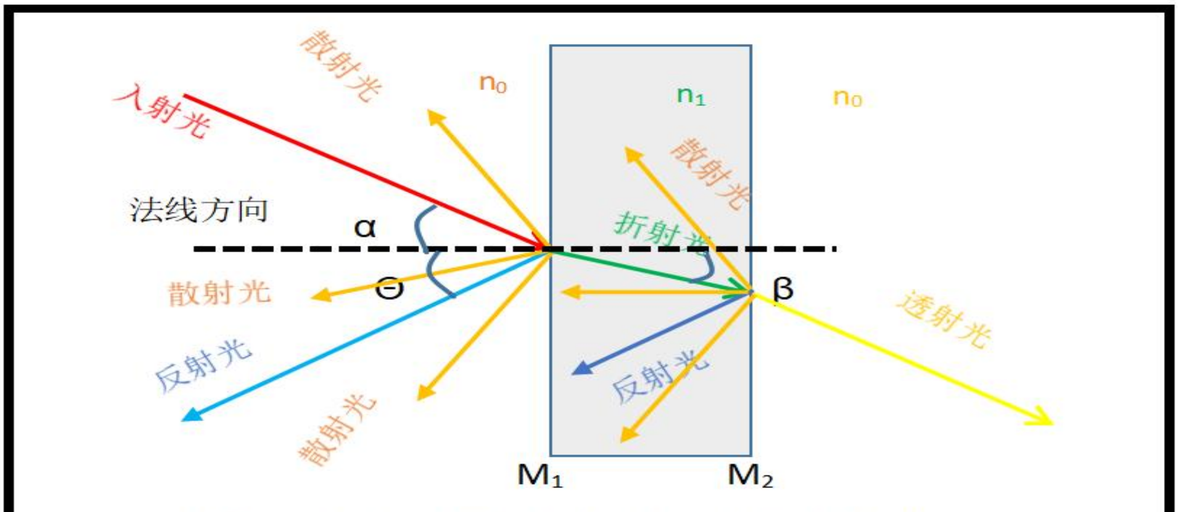
以上内容摘自［**百度百科**］。

Second, the mechanism analysis of the reflected light half-wave loss phenomenon

二、反射光存在的半波损失现象的机理分析

1. Phenomena and rules of interaction between light and transparent medium

1 、光与透明介质的相互作用现象与规律



图一：光遇透明介质时的相互作用规律图示

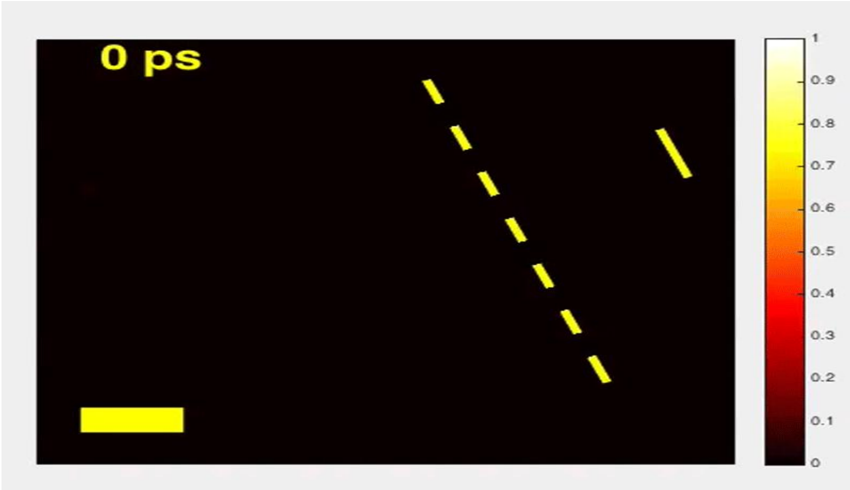
Figure 1: Schematic diagram of light interaction with transparent medium

As shown in Figure 1, when n0 = 1 and n1>1, the incident light will generate reflected, scattered and refracted/transmitted light at the medium interface M1 and M2. This is unexplained by photons of so-called single frequency that carry kinetic energy and momentum proportional to their frequency: photons shot at the same Angle into a plane should not appear to be flying around the plane。

如上图一所示：当 n_0＝1、n_1>1 时，入射光在介质界面 M_1 和 M_2 处均会产生反射、散射和折射/透射光。这是用所谓的频率单一且携带与其频率成正比的动能和动量的光子无法解释的：同一角度射向平面的光子不应该在平面处出现到处乱飞的景象。

2. The actual condition of light in transparent medium and vacuum

2、光在透明介质和真空中的实际状况



(GIF illustration: The left side of the long dotted line is the light guiding medium, while the space between the right side and the short solid line is the vacuum, and the short solid line is the mirror)

（动图说明：长虚线左侧为导光介质，而其右侧至短实线间为真空，短实线为反射镜）

Figure 2: Motion path of light in medium and vacuum

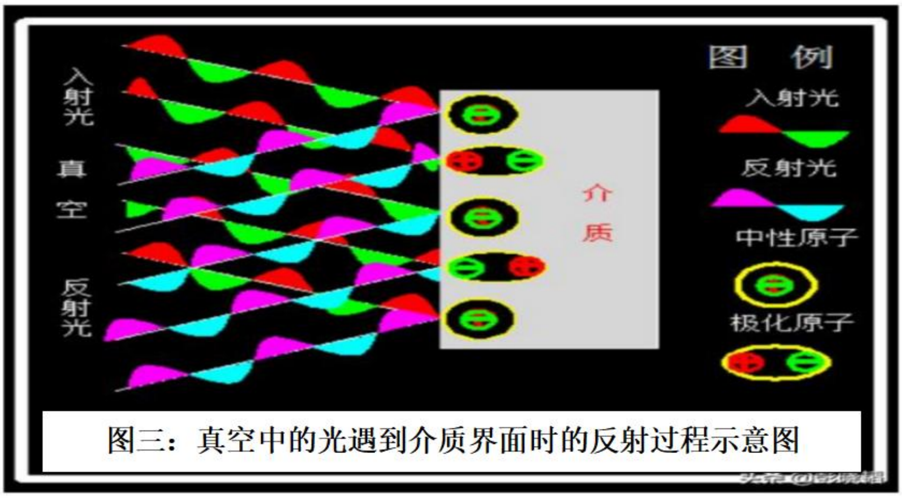
图二：光在介质及真空中的运动轨迹动图

As shown in Figure 2, in a transparent medium with refractive index n>1, every point along the path of refracted light will become a sub-light source and radiate secondary light in all directions. However, in a vacuum with refractive index n = 1, the changing electric field cannot affect the magnetic field, and the changing magnetic field cannot affect the electric field, so the so-called electromagnetic wave excited by each other will not be generated, so that secondary light radiating in all directions will not be generated. This causes the spherical pulses of light in the vacuum region of the GIF not to be seen.

如上图二所示：在折射率 n>1 的透明介质内部，折射光经过的路径上的每个点都会成为一个子光源并向各个方向辐射次生光；而在折射率 n＝1 的真空中，因变化的电场并不能感生磁场，变化的磁场也不能感生电场，从而不会产生所谓的电磁相互激励的电磁波，从而不会产生次生的、向各个方向辐射的次生光。这就导致了动图中真空区域的球状光脉冲不能被看见。

3. The actual action process of the interface between light and medium

3、光与介质界面的实际作用过程



图三：真空中的光遇到介质界面时的反射过程示意图

Figure 3: Schematic diagram of the reflection process of light in a vacuum when it meets a medium interface

As shown in Figure 3: when the incident light reaches the dielectric interface, the electric and magnetic fields generated by it will make the electrons in the atoms on the dielectric interface change their motion state in a completely opposite direction to the nucleus, so that the atoms are polarized into electric dipoles with electric dipole moment with the same main frequency as the incident light.

如上图三所示：当入射光到达介质界面时，其产生的电场和磁场就会使介质界面上的原子中的电子与原子核朝完全相反的方向改变运动状态，从而使原子被极化为与入射光主频相同的时变电偶极矩的电偶极子。

According to the fact that the electron and proton carry the same amount of charge but have opposite electrical properties and the mass difference is more than 1832 times. Without considering the mass of neutron, under the action of the same external electric field, the acceleration, velocity and displacement of the electron are about 1832 times that of the proton and the acceleration direction is the opposite. If we consider a nucleus consisting of neutrons and two or more protons, the electrons in the atom are subjected to the same external electric field as the nucleus, and the acceleration of the electrons is much greater than that of the nucleus. Therefore, when the frequency of the external electric field is very high, we can temporarily ignore the effect of the acceleration, velocity and displacement of the nucleus in the electric field, and only consider the effect of the acceleration, velocity and displacement of the electron on the time-varying dipole moment of the atomic polarization and the resulting secondary electric dipole field.

根据电子与质子所携带的电荷量相同但电性相反且质量相差 1832 多倍，在不考虑中子质量的情况下，在同样的外电场作用下，电子的加速度、速度和位移量是质子的 1832 倍左右且加

速的方向正好相反。如果考虑中子和二个或二个以上的质子构成的原子核的话，则原子中的电子与原子核在同样的外电场作用下，电子的加速度比原子核的大得更多。因此，当外电场的频率很高时，我们可以暂时不考虑原子核在电场中的加速度、速度和位移的影响，而只考虑电子的加速度、速度和位移量对原子极化为时变电偶极矩的影响以及其产生的次生电偶极子场。

When the electron takes the origin as the center of the circle, it moves in the X and Y axis plane with constant velocity and the equations of motion are: X = R0cos2π f0t, Y = R0sin2π f0t; VX=-2π f0R0sin2π f0t, VY=2π f0R0cos2π f0t; aX = -4(π f0)2R0cos2π f0t, aY = -4(π f0)2R0sin2π f0t. And suppose that when they change their distance from the origin under the action of resonant electric field E = Asin2π ft along the X-axis, the centripetal force maintaining their circular motion still does not change (in fact, there is change, but when the frequency of external electric field is high, its influence can be temporarily ignored), then their equations of motion are respectively:

当电子以原点为圆心，在 X、Y 坐标轴平面内作恒定速度圆周运动且运动方程为：$X=R_0\cos 2\pi f_0 t$、$Y=R_0\sin 2\pi f_0 t$；$V_X=-2\pi f_0 R_0\sin 2\pi f_0 t$、$V_Y=2\pi f_0 R_0\cos 2\pi f_0 t$；$a_X=-4(\pi f_0)^2 R_0\cos 2\pi f_0 t$、$a_Y=-4(\pi f_0)^2 R_0\sin 2\pi f_0 t$。并假设它们在沿 X 轴方向的谐振电场 $E=A\sin 2\pi ft$ 的作用下改变与原点的距离过程中，维持其作圆周运动的向心力仍然不会因此发生变化（实际上是存在变化的，但当外电场频率较高时，可暂时不考虑其影响）时，则它们的运动方程分别为：

加速度：$a_X=QA\sin 2\pi ft/m-4(\pi f_0)^2R_0\cos 2\pi f_0t$　　$a_Y=4(\pi f_0)^2R_0\sin 2\pi f_0t$

速　度：$$V_x=\int a_x dt=\int\left(\frac{QA\sin 2\pi ft}{m}-4(\pi f_0)^2R_0\sin 2\pi f_0t\right)dt=-\frac{QA\cos 2\pi ft}{2\pi fm}-2\pi f_0R_0\sin 2\pi f_0t$$

$V_Y=2\pi f_0R_0\cos 2\pi f_0t$　　（公式 1）

位移量：$$X=\int V_x dt=\int\left(-\frac{QA\cos 2\pi ft}{2\pi fm}-2\pi f_0R_0\sin 2\pi f_0t\right)dt=\frac{QA\sin 2\pi ft}{4(\pi f)^2m}+R_0\cos 2\pi f_0t$$

$Y=R_0\sin 2\pi f_0t$

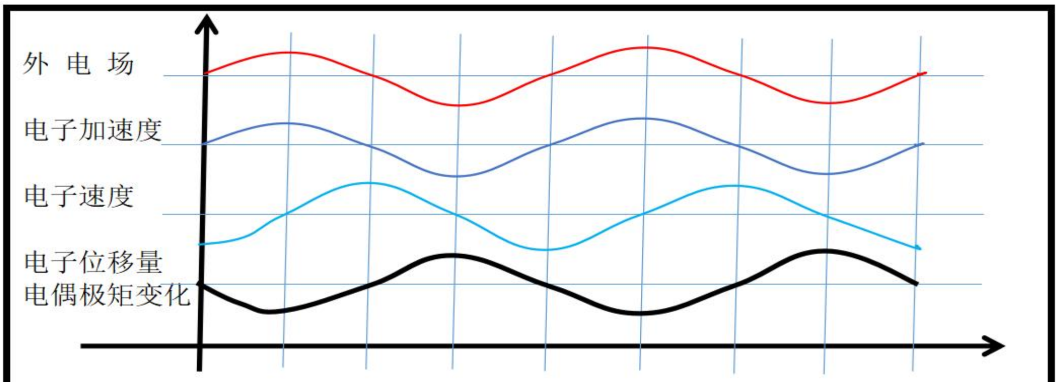
After deducting the original acceleration, velocity and displacement, the pure acceleration, velocity and displacement under the external electric field are respectively:

扣除其原来的加速度、速度和位移量，则在外电场作用下的纯粹加速度、速度和位移量分别为：

加速度变化量：$\triangle a_X=QA\sin 2\pi ft/m$

速度变化量：$$\Delta V_x=\int \Delta a_x dt=\int\left(\frac{QA\sin 2\pi ft}{m}\right)dt=-\frac{QA\cos 2\pi ft}{2\pi fm}$$　　（公式 2）

位移量变化量：$$\Delta X=\int \Delta V_x dt=\int\left(-\frac{QA\cos 2\pi ft}{2\pi fm}\right)dt=-\frac{QA\sin 2\pi ft}{4(\pi f)^2m}$$



图四：原子中的电子在外电场作用下的运动状态变化示意图

Figure 4: Schematic diagram of motion state of electrons in atoms under external electric field

As can be seen from the above formulas and Figure 4, the time-varying dipole moment of the polarization element under the action of the sine wave external electric field is exactly half a period different from the external electric field, and the secondary electric field generated by it is, of course, exactly half a period different from the external electric field. This is why reflected light has a half-wave loss. It is also the fundamental reason why the speed of refracted light is lower than the speed of incident light in the photophobic medium. Because it takes half a cycle from the polarized element in the reflected light polarized medium to the polarized element to produce secondary light. When the number of polarized elements per unit length increases, the time needed to lose will naturally increase, and the speed of light inside the medium will be slower (since atoms and molecules can be regarded as vacuum, the speed of light between atoms and molecules is constant relative to the speed of light in vacuum).

从以上各公式和图四可知：在正弦波外电场作用下的极化元的时变电偶极矩与外电场正好差半个周期，其产生的次生电场当然也就与外电场正好相差半个周期。这也是为什么反射光存在半波损失的原因所在。也是折射光为什么速度会低于光疏介质入射光速度的根本原因所在。因为从反射光极化介质中的极化元到极化元产生次生光需要消耗半个周期的时间。当单位长度内的极化元数量越多，需要损耗的时间自然也就越多，介质内部的光速也就越慢（由于原子与原子、分子与分子间可视为真空，其间的光速相对介质恒定为真空中的光速）。

In short, refracted light in the medium is not a variant of incident light, but a new secondary light produced by polarized elements in the medium.

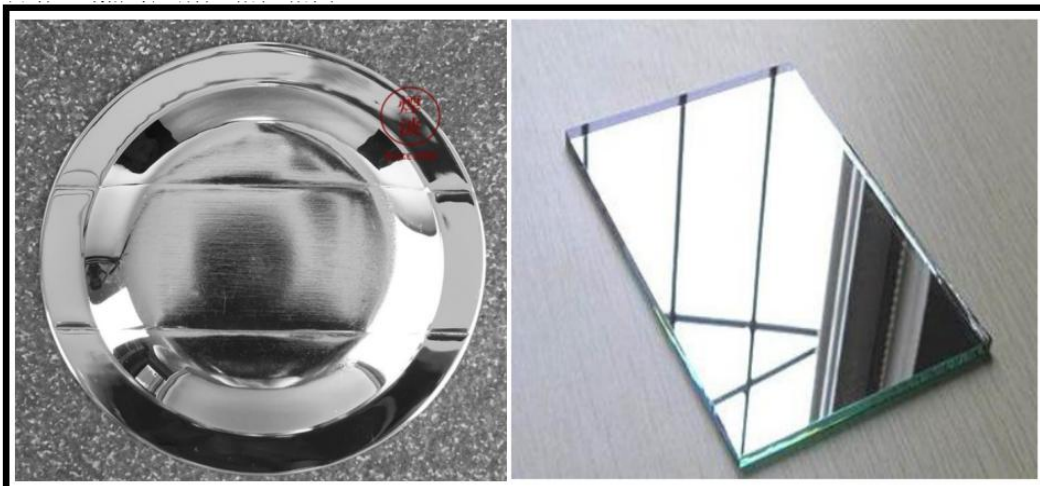
总之，介质中的折射光不是入射光的变种，而是由介质中的极化元产生的全新的次生光。

Three. Analysis of the cause of no half-wave loss when the light inside the photodense medium meets the photophobic medium

三、光密介质内部的光遇到光疏介质时的反射光无半波损失的原因分析

Because the light inside the medium is the secondary light generated by the medium itself, and the generation process is: each regeneration cycle will consume half of the cycle time. Therefore, the phase of light inside the medium does not change continuously. However, the phase of electromagnetic field at the interface of different media is determined by the direction of polarization of atoms at the interface. Both incident light and reflected light are generated by atoms at the same interface. Uniqueness determines the uniqueness of their phase, and the phase must be the same. At the junction of the optically dense medium and the optically sparse medium, there are more atoms on one side of the optically dense medium than on the other side of the optically sparse medium. The reflected/scattered and transmitted light generated at this junction are secondary light produced by atoms on both sides of the interface, but mainly generated by atoms on one side of the optically dense medium. Therefore, of course, the light reflected back into the optically dense medium at the interface is of the same phase as the incident light.

由于介质内部的光为介质自身产生的次生光，且产生过程是：每个再生周期都会消耗掉半个周期的时间。因此，介质内部的光的相位并不是连续变化的。但在不同介质界面处的电磁场相位是由界面处的原子的极化方向决定的，入射光与反射光都是同一界面处的原子产生的，唯一性就决定了其相位的唯一性，相位必须是相同的。在光密与光疏介质界面交接处，光密介质一侧的原子数量多于光疏介质一侧，在此交接处所产生的反射／散射、透射光是由界面两侧原子共同产生的次生光，但主要由光密介质一侧的原子产生，因此，界面处的反射回到光密介质内部的光当然与入射光相位相同。



银面　　镜面

图五：银面与镜面实景图

Figure 5: Silver and mirror images

As can be seen from Figure 5, the silver surface still retains its metallic luster, and its reflected light intensity is much less than that of the mirror. The reflection of the mirror is almost omnidirectional. So why does a thin layer of silver deposited on flat glass create something so reflective? This is because the super flat glass itself is mainly produced by refracted light, and the intensity of reflected and scattered light is very weak. When the silver atoms are closely bonded with the flat glass, the arrangement of the silver atoms shows a high regularity, and the secondary light produced by the silver atoms is mainly reflected light, while the intensity of the scattered light is very weak. As a result, the mirror becomes an almost perfect reflectivity object. However, the phase of the secondary light generated by the atoms on both sides of the contact surface of the glass and silver atoms is in the same direction, and there is no obvious difference in phase, which will not cancel each other. That's why specular reflection is so powerful.

从上图五可知：银面仍保留着金属光泽，其反射光的强度远小于镜面。而镜面的反射几乎是全方向全反射式的。那么，为什么一层薄薄的银元素沉淀在平整的玻璃上后，就会形成反射能力如此之强的物件呢？这是因为平整度超高的平面玻璃本身是以产生折射光为主的次生光，反射和散射光的强度十分弱小。当银原子与平面玻璃紧密接合后，银原子的排列呈现高度地有规律性，其产生的次生光以反射光为主，而散射光强度十分微弱。因此，镜面就成了反射率高到几乎完美程度的物件。而玻璃与银原子的接触面处两侧的原子产生的次生光的相位是同向的，且相位不存在明显差异，不会出现相互抵消的现象。这才是镜面反射能力如此之强的原因所在。

Fourth, the physical significance of the half-wave loss phenomenon of reflected light

四、反射光存在的半波损失现象的物理意义

1. It is directly proved that reflected light is not incident light or part of incident light

１、直接证明了反射光并非入射光或入射光的一部分

Because, if the reflected light is the light after the incident light is reflected by the medium interface and only changes the direction of motion, then the phase should not be half a period. At the same time, there should be no weak scattered light.

因为，如果反射光是入射光被介质界面反射而仅改变了运动方向后的光，则相位不应该相差半个周期。同时，也不应该出现强度较弱的散射光。

2. It is directly proved that light will make the medium become a secondary source of light when it encounters the medium

２、直接证明了光遇到介质后会使介质成为次生光源

This is because only the reflected and scattered light, which can be in any direction, is the secondary light produced by the medium to explain the half-cycle phase difference between the reflected light and the incident light.

因为，只有反射、散射光是由介质产生的次生光才能解释反射光为什么会与入射光间存在半个周期的相位差，而散射光可以是任意方向。

3, can be used to explain a variety of physical phenomena and experimental results

３、可以用来解释多种物理现象与实验结果：

3.1. The reflected/scattered light intensity varies greatly with the same material but different surface smoothness

３.1、同材质但表面平整度不同时的反射/散射光强度差异大

This is because when the surface roughness is different, the phase of the sub-light source composed of atoms and molecules on the surface is different, so the superposition result is different. This leads directly to changes in the intensity of reflected and scattered light.

这是因为表面平整度不同时，表面上各原子和分子构成的子光源产生的次生光的相位存在差异，从而其叠加结果就不同。这就直接导致了反射和散射光强度的变化。

3.2 With the same material but different surface smoothness, the reflected light color difference is huge

3.2、同材质但表面平整度不同时的反射光颜色差异巨大

This is because when the surface roughness is different, the superposition of secondary light generated by atoms and molecules on the surface will result in the enhancement of light of certain frequency and suppression of light of other frequencies, thus resulting in the color of reflected and scattered light different from that of incident light.

这是因为表面平整度不同时，由表面上的原子和分子产生的次生光叠加后会出现某此频率的光得到加强，另一些频率的光受到抑制，从而导致反射和散射光的颜色不同与入射光的颜色。

3.3. The absorption rate of graphene is generally 2~3%. But a special process to create a texture on the surface can become a super-absorbent material, which can absorb more than 90 percent of light

3.3、石墨烯的吸光率一般为 2~3%。但通过特殊工艺使其表面产生某种纹理就会成为超级吸光材料，其吸光率可达 90%以上

This is because the superposition of light produced by atoms and molecules on the surface varies depending on the shape of the surface. When the surface texture is just enough that light in visible wavelengths is superimposed on each other and most of it cancelling out, the intensity of the reflected light is greatly reduced, resulting in what is known as a large increase in absorbance.

这是因为表面形状不同时，由表面上的原子和分子产生的次生光叠加后的结果不同导致的。当表面的纹理正好可以使可见光波段内的光相互叠加后大部分被相互抵消时，反射光强度就会大大被削弱，从而导致了所谓的吸光率大幅度提高。

3.4, why the world has the colorful color of red leaves green fruit yellow

3.4、为何世间有花红叶绿果黄的丰富多彩颜色

This is because atoms in substances composed of different elements and groups of elements are subjected to different electromagnetic forces from other neighboring atoms and molecules, and the dipole moment of the electric dipole generated under the action of incident light is naturally different, and the change law with time is also different. As a result, the main frequency of the secondary light produced will also be different. The color of an object's surface is determined by what is called the dominant frequency of reflected light, hence the rich variety of colors.

这是因为不同元素及元素群组所组成的物质中的原子所受到邻近其他原子和分子的电磁作用力不同，其在入射光作用下产生的电偶极子之偶极矩自然也不同，随时间的变化规律也不尽相同。因此，其产生的次生光的主频也会不同。而物体表面的颜色是由所谓的反射光的主频决定的，因此就出现了丰富多彩的各种各样的颜色。