Light beam traveling with varying energy

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Light emitted from a multiple reflection device using a mirror and a half-mirror does not show interference fringes when the relative angle between the mirrors is zero, and the energy of the incident light and the outgoing light coincide at each point. On the other hand, when the relative angle is non-zero, interference fringes are observed depending on the angle. We have reported that the total energy of the incident and outgoing beams do not match (that is, the law of conservation of energy does not hold) when the relative angle is small (the fringe spacing is wide) and the incident beam width is narrow. Furthermore, the light beam emitted from this multiple reflector has the interesting property of changing in intensity as it propagates. We have experimentally confirmed this change.

I. INTRODUCTION

It is well known that when light is incident on a thin film, the sum of the energy of the reflected and transmitted waves produced by multiple reflections matches the total energy of the incident light[1]. Such an energy coincidence (energy conservation law) holds not only in electromagnetism but also in many other fields of physics[2–4].

In a multiple-reflection system using a half-mirror (HM) and a mirror, if the relative angle between the mirrors is made very small, the distance between the bright lines of the interference fringes increases to several millimeters or more. When a laser beam with a width narrower than the distance between the bright lines of the interference fringes is incident on this device, the intensity of the outgoing light increases relative to the incident light intensity[5]. Furthermore, it was suggested that the light beam emitted from this device propagates with varying energy[5]. In this report, we present the results of an experimental verification of the increase or decrease in light intensity as a function of the beam propagation distance.

II. CHANGE IN ENERGY DUE TO MULTIPLE REFLECTION INTERFERENCE

The reflection and transmission of light by the half-mirror and the mirror of the multiple reflection interferometer are shown in Figure 1. A beam vertically incident on the half-mirror is divided into p_0 light reflected by the half-mirror, p_1 light reflected once by the mirror and emitted, p_2 light reflected twice by the mirror, p_3 light reflected three times, and so on. If the relative angle between the half-mirror and the mirror is θ, the light is reflected at angles of $0°$, $2\theta°$, $4\theta°$, and $6\theta°$, respectively.

If the distance from the surface of the half-mirror to the observation surface is L and the wavelength of light

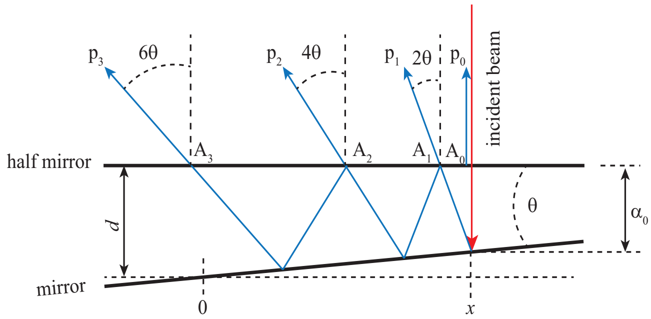

FIG. 1: Schematic diagram of multiple reflections by a half-mirror and a mirror: light incident at point A_0 is repeatedly reflected between the mirror and the half-mirror and then emitted in each direction. The distance between the mirror and the half-mirror at $x = 0$ is d and the angle between the mirror and the half-mirror is θ.

is λ, the electric field at the beam position L is given by

$$E = -r\exp\left(\frac{-i2\pi L}{\lambda}\right) + r\sum_{m=1}^{\infty}(-r)^m \exp\left(\frac{-i2\pi s_m}{\lambda}\right) \tag{1}$$

$$\begin{aligned} s_m &= \sum_{n=1}^{m}\frac{\alpha_0\cos\theta}{\cos((2n-1)\theta)}\left(\frac{1}{\cos((2n-2)\theta)}\frac{1}{\cos(2n\theta)}\right) \\ &+ \frac{L}{\cos(2m\theta)} \\ \alpha_m &= d - x_m\tan\theta \\ x_m &= x + L\tan(2m\theta) \\ &+ \sum_{n=1}^{m}\frac{\alpha_m\cos\theta}{\cos((2n-1)\theta)}\left(\tan((2n-2)\theta)+\tan(2n\theta)\right) \end{aligned}$$

where the first term is the light wave reflected at point A_0. The time component was neglected because of the simultaneous measurement (see Reference[5] for details). It was also assumed that the phase changes when light reflects off the upper surface of the half-mirror and that there is no phase change when light reflects off the lower surface. The calculated light intensity would be the same if the situation were reversed). For further simplification, the amplitude reflectance r and amplitude transmittance t were assumed to be equal and $r^2 = t^2 = 1/2$.

Approximating $(\cos\theta \approx 1, \tan\theta \approx \theta)$ by assuming that θ is small in equation (1), we obtain the following equation.

$$\begin{aligned}
\alpha_m &\approx \alpha_0 - 2m\theta^2(md + L) \\
s_m &\approx 2\alpha_0 m + L - (2\theta^2 L)m^2 \\
|E|^2 &\approx (r^2 + r^4 + r^6 + \cdots) \\
&+ 2r^3 \cos\left(2\pi \frac{2(d - x\theta) - 2\theta^2 L}{\lambda}\right) + \cdots \\
&= 1 + 2r^3 \cos\left(2\pi \frac{2(d - x\theta) - 2\theta^2 L}{\lambda}\right) + \cdots \quad (2)
\end{aligned}$$

The second term in equation (2) indicates that the interference fringe spacing in the x-axis and L-directions is of the order of $1/\theta$ and $1/\theta^2$, respectively. It indicates that the intensity of the light beam emitted from the multiple reflector changes as it propagates. Figure 2 shows an example of calculation of the dependence of total light intensity on the travel distance of the outgoing beam when $d = 2mm$ and $\theta = 0.01°$ (Equation (1) was used in the calculation).

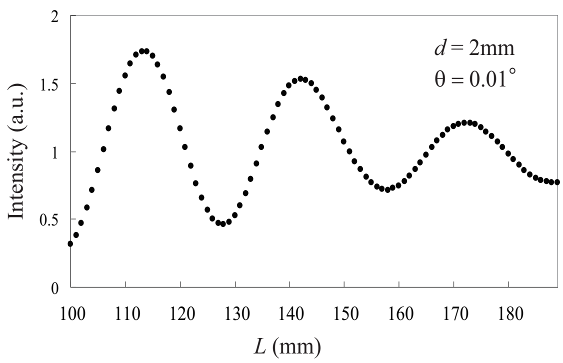

FIG. 2: Total light intensity relative to the distance L from the half-mirror to the observation point. $(d = 2mm, \theta = 0.01°)$

III. MULTIPLE REFLECTION INTERFEROMETER AND EXPERIMENTAL RESULTS

Figure 3 shows an interference system using multiple reflections. Light emitted from a laser (635 nm) is spread along a line by a line generator (fan angle = 30°) and passes through a Glan-Thompson polarizer (P polarizer). The P-polarized beam goes straight through the polarizing beam splitter (no reflection), passes through the $\lambda/4$ wave plate, is repeatedly reflected by a half-mirror and mirror, and then passes through the $\lambda/4$ wave plate once again. The beam, which is S-polarized by the wave plate, is perfectly reflected by the polarizing beam splitter, and the total light intensity is measured by a $10mm$ square photo diode (PD).

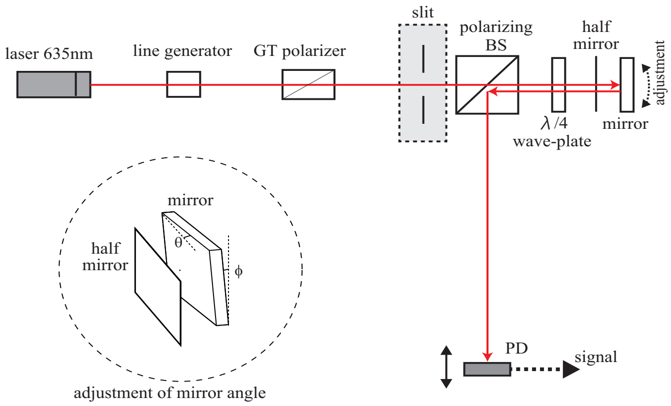

FIG. 3: Multiple-reflection interferometer: laser light passes through a line generator, a polarizer (P polarization), and a slit and travels straight through a polarizing BS. The light reflected by the mirror and half-mirror many times becomes S-polarized by the waveplate and is detected by the PD.

Figure 4 shows the measurement results when $\theta = 0.045°$ and the beam width is $1mm$ (black circles). The intensity changes as the beam propagates, and its amplitude gradually decreases. The white circle in Figure 4 shows the measured value when the half-mirror in Figure 3 is removed; the beam intensity was adjusted so that the white and black circles coincide at $L = 165mm$. When the half-mirror is removed, the incident beam is reflected by the mirror and emitted as it is, so the beam intensity is almost constant regardless of the position.

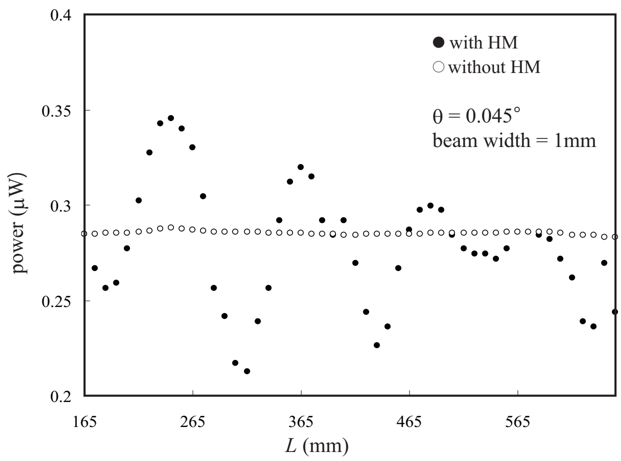

FIG. 4: Beam intensity vs. propagating distance of the beam emitted from the multiple reflector: The black circle shows the change in beam intensity when the beam width is $1mm$ and $\theta = 0.045°$. The white circle shows the beam intensity when the half-mirror is removed, which is almost constant regardless of the position.

IV. SUMMARY

Experiments showed that beams emitted from a multiple reflection interferometer propagate with increasing and decreasing energy. This result also violates the conservation law of energy. Since the energy of light corresponds to the number of photons, it indicates that the beam propagates while changing the number of photons. It is not known where these photons appeared and disappeared from.It is natural to interpret the number of photons as generated in proportion to the square of the amplitude of the electric field at each position. Various interpretations of the interference effects of light have been proposed in quantum mechanics[6]; in the De Broglie-Bohm theory, photons move along a fixed path while being limited by the quantum potential[7]. Therefore, the total number of photons must remain constant as the beam propagates, which is inconsistent with the results of this experiment. It seems necessary to reexamine the relationship between the energy of light and the number of photons and the electromagnetic field.

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