621. Development of laser beam light intensity control system

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Abstract. The paper proposes a novel laser beam light intensity control system, which functionality is based on piezoelectric actuators and special membrane that is comprised from two gratings. Geometrical adjustment between adjacent pores in both plates results in zero light intensity through the membrane when no control signal is activated. Displacement of one of the control membrane plates with micro pores generates effects which are exploited for laser beam flow power control.

Keywords: light intensity control, piezoelectric actuator, laser.

Introduction

In this era of new technologies many requirements are raised for precision equipment such as small size, versatility, reliability, efficiency, wide operating temperature range and speed, abilities to function in vacuum and radiation environment. It is well known that piezoelectric actuators [1-3] satisfy most of the requirements including wide temperature range in which they can operate, impassibility for electric, magnetic and radiation fields, high speed, low electromagnetic interference, high power at low speeds, self blocking, high power and weight ratio. Piezoelectric actuators are characterized by a very simple design, small size and relatively low cost, suitable for use in precision positioning systems [4-6]. Therefore, this type of actuator was chosen for the design of laser beam power control device. Laser beam transmission membrane consists of two plates with micro pores and one of the plates depending on the type of actuators may carry out the linear motion in lateral *x* or *y* directions. Light intensity transmission parameters depend on any movement of the membrane plates with micro pores.

An accurate and relatively inexpensive laser beam power control device was developed by adjusting the possibilities of positioning of piezoelectric actuators as well as positions of micro pores that result on the membrane. The device may also be designed of different size because the variety of actuator dimensions is very large. Therefore it can be widely adapted to both high and low intensity laser beam control.

Construction of the laser beam flow power control system

The article analyzes light intensity transmission system, which might be used for power control of the laser beam (Fig. 1). Flowing through the cylindrical lens, laser beam is expanded and passes through membrane, which is structured from round, hexagonal or other form micro pores located in nods of rectangular regular or translated grating. One or two piezoelectrically-controlled grating plates are able to perform translation motion in lateral *x* or *y* directions. In the case micro pores match, we obtain maximum light intensity, whose value depends on transmission parameters of the micro pores. When a mobile plate moves in *x* or *y* direction, the light intensity of the laser beam is varied from maximum to minimum (closed, opened or transitional variants obtained).

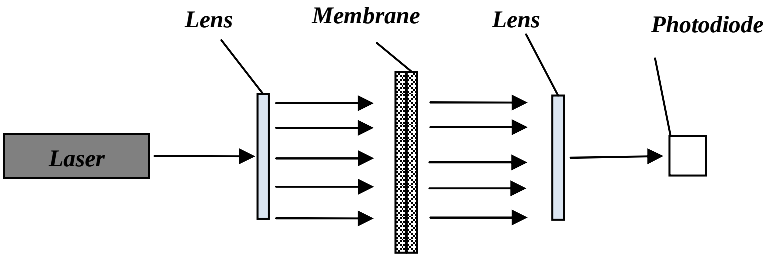

Fig. 1. The laser beam light intensity control system

When micro pore of one plate match closed areas of another plate, the light intensity transmission is completely closed. When the membrane laser beam passes through a second lens it is focused onto photodiode for the further analysis. Due to piezoelectric actuation, such a laser beam transmission system is characterized by fast response time and precise control of laser beam light intensity.

Choosing piezoceramic actuator for laser beam light intensity control equipment

The article analyses laser beam light intensity control equipment, which makes linear motions, and thus requires choosing such type of piezoelectric control that would correspond to set conditions and theoretically and experimentally analyze their work parameters.

Such world-known companies as Noliac A/S, Ferroperm Piezoceramics A/S, Physik Instrumente GmbH & Co (PI), Cedrat Group, Piezomechanik GmbH, and others offer large range of piezoceramic actuators that are able to perform linear motions, but the supply of actuators making at least 100 μm movement is limited.

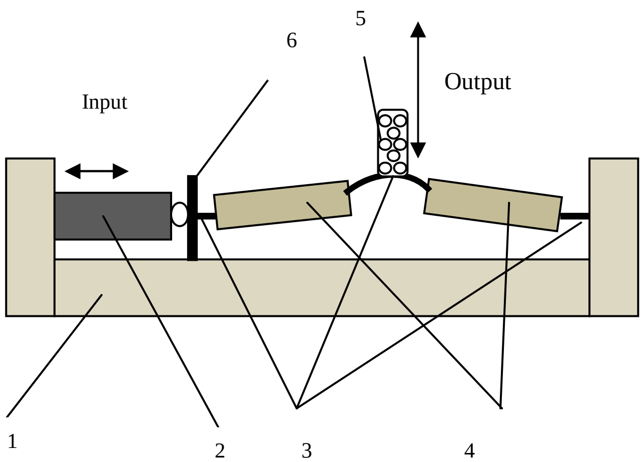

Fig. 2. Piezoactuator with elastic displacement amplification link: 1 - frame 2 - piezoelement, 3 - elastic joints, 4 - solid element, 5 - plate, 6 - elastic support

In order to obtain a complete control of light intensity, i.e. closing and opening, suitable piezoelectric actuator, able to generate at least 100 μm translation motion is necessary. Literature analysis disclosed that such work can be accomplished using bending [7, 8] and stack actuators as well as those with elastic displacement amplification link [9-11]. Further experimental research was performed using an actuator, developed at Kaunas University of

Technology, which corresponds to the required conditions, i.e. ability to perform at least 100 μm translational motion.

The piezoelectric laser beam device (application number 2009 090, Authors: R. Bansevičius, A. Bubulis, V. Jūrėnas and etc.) has been developed and patented at Kaunas University of Technology. Its control mechanism (onward referred to as actuators) may be utilized and for the design of the considered light intensity control device.

Since the actuator had kinematic displacement amplification link, the initial displacement motion of piezoelectric element was amplified up to 10-30 times.

Piezoelectric actuators with kinematic displacement amplification link usually involve lever mechanisms. Displacement motion may be intensified to even higher extent by using multilevel lever systems. But due to additional inertia of mechanic units and performance characteristics of joints and levers, dynamic characteristics of such control (maximum work frequency, power generated) are worth than those of piezoelement used for its actuation. Piezoactuators of such type may be used in structures of the analyzed light intensity control equipment too (Fig. 2).

In order to increase the maximum modulation frequency of the membrane plate with micro pores control, it is necessary to minimize the inertia of the moving units without reducing the amplification coefficient of displacement, i.e. to reduce the weight of the elastic chain. For this purpose was proposed and built experimental model of the actuators according to the diagram given in Fig. 2, which is used for design of the light intensity control device.

Experimental study of dynamic characteristics of actuators with elastic displacement amplification link

Testing and manufacturing of the most of piezoceramic actuators is relatively expensive, thus preliminary simulation and testing of its components is extremely important. In order to use all piezoelectric possibilities of the right positioning of steel plates, precise selection of suitable actuator and analysis of its performance as well as work characteristics is necessary.

The article analyzes the developed piezoactuator with elastic displacement amplification link for linear motion, patented at Kaunas University of Technology (patent application no. 2009 090 R. Bansevičius, A. Bubulis, V. Jūrėnas authors, etc.) (Fig. 3).

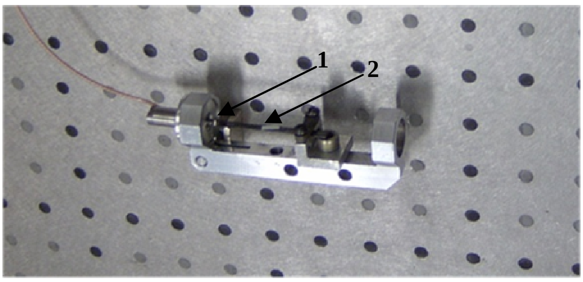

Fig. 3. Linear motion actuator with a piezoelement 1 and the elastic displacement amplification link 2

Elastic link of actuators in this model (Fig. 3) has been made from narrow and thin long strips (strip size 50x5x0,6 mm), which were made from epoxy resin impregnated carbon fiber 50 mm. Elastic link was stimulated by piezomultilayer actuator PSt/4/20 VS9 (Piezomechanik GmbH, Germany).

To achieve this aim the experiments were carried out at the KTU Mechatronics Centre for Research, Studies and Information. Equipment used in the experiment is shown in Fig. 4. It was composed of programmable signal generator (Aligent 33220, 20 MHz), voltage amplifier EPA 104, laser Doppler vibrometer Polytec(Vmax=10 m/s, frequency bandwidth 0.5 Hz - 1.5 MHz, resolution from 0.1 to 2.5 (mm/s)/√Hz)), photo diode OP905, analog data acquisition board (National Instruments PCI 5102, 20 MS/s) and a computer with installed LabView software.

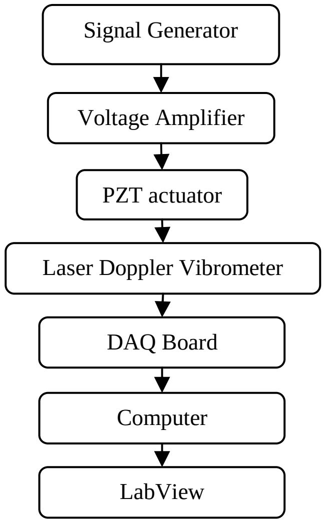

Fig. 4. An experimental setup for investigation of dynamic characteristics of the piezoactuator (performing a linear motion)

A specific program was designed for the measurement data to be stored and processed in environment of LabView graphical programming, allowing determination of amplitude-frequency characteristics for the experimental output link (elastic link).

The experiments allowed to determine the displacement of the piezoactuator output link (elastic link) by changing the excitation voltage. As it is known, ferroelectric material, which is used in actuators, has typical hysteresis of displacement, voltage and force. In addition to hysteresis of the piezoelement, it can also be increased by additional kinematic chains (levers, hinges, rails), which are a part of the piezoactuator.

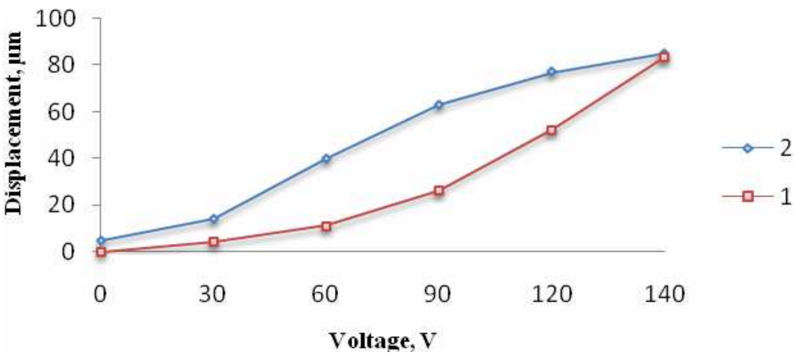

Fig. 5. Displacement of mobile plate of the membrane versus applied voltage to the piezoactuator (static characteristic of hysteresis loop)

The dependence presented in Fig. 5 demonstrates the determined hysteresis loop. It can be observed that increase of the excitation voltage from 0 V to 60 V leads to increase of displacements (curve 1), while reduction of the voltage brings the displacements back to zero (curve 2). The maximum hysteresis of the tested piezoactuator reached 30 %. Thus, in order to increase positioning accuracy of this piezoactuator it is necessary to determine the feedback in accordance to displacement.

The same experimental setup (Fig. 4) was used to establish the dependence of displacement of the mobile plate as a function of excitation frequency by maintaining a constant voltage supply (70 V) of the piezoactuator. The dependence (Fig. 6) reveals that the maximum displacement of piezoelectric actuators (peak to peak amplitude of vibration) will reach up to 250 µm, when it moves at the resonant frequency of 581 Hz. Further increase of the frequency of the vibration leads to significant decrease of the displacement and above 800 Hz it drops below the resonant level, i.e. 100 µm.

It should be mentioned that the use of this piezoelectric actuator cannot provide high permeability but the light intensity through the membrane can be controlled to a sufficient extent. Working across our entire analyzed frequency range a 100 µm displacement is achieved, which is needed to perform full light intensity control, i.e. full opening and closing of the membrane.

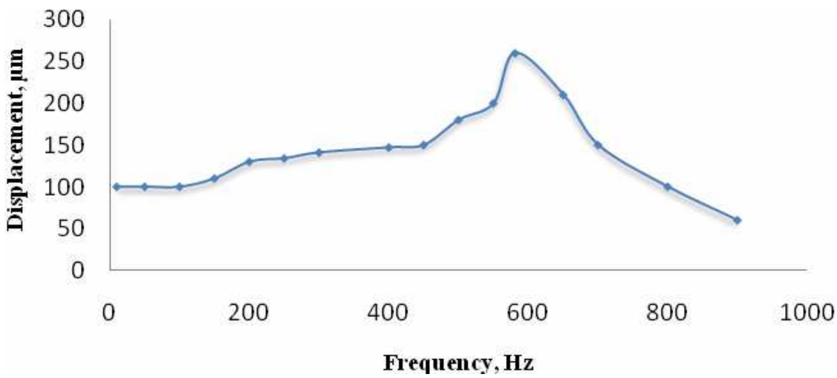

Fig. 6. Displacement of mobile plate of the membrane as a function of excitation frequency

Numerical and experimental study of light flow permeability through the membrane, composed of plates with hexagonal micro pores located in shifted rectangular array of nodes

The publication analyzes membranes, when both plates are in the same dimensional position and mobile plate performs linear motions in two directions (*x* and *y* axis-wise) (Fig. 7).

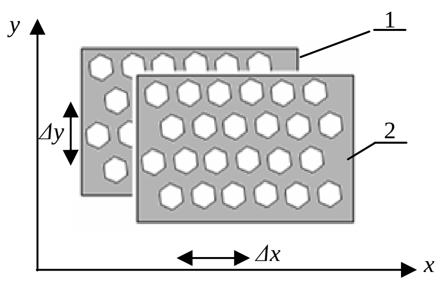

Fig. 7. Membrane diagram when plates are in the same dimensional position: 1 – mobile plate, 2 – steady plate

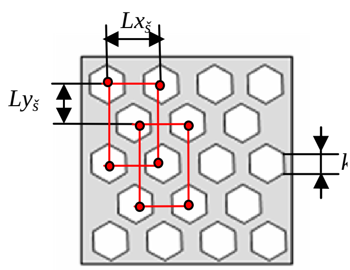

Fig. 8. Structure of plates where hexagonal micro pores are located in shifted rectangular array of nodes

Plates of suitable geometric parameters are necessary in order to develop a membrane for linear motion light intensity control equipment (Fig. 7) that would enable complete light intensity control (close, open and intermediate positions). Naturally, the distances $Lx_š$ and $Ly_š$

(Fig. 8) in hexagonal pores of plates, present in nods of rectangular regular or translated grating, should be at least of double size that the diagonal *k* of the hexagon. This is the only way to completely close the light intensity translating the plates horizontally in respect to each other.

The research was performed with a membrane that consisted of plates whose hexagonal micro pores were set in rectangular form in nods of translated grating. Numerical simulation was performed using certain parameters of plates (Fig. 9). The results obtained were compared with experimental ones. Simulation was started when micro pores did not match and membrane appeared in closed position. Then, the mobile plate was translated every 0.02 mm in *x* axis direction (Fig. 10). After reaching maximum light intensity, the plate was translated by 0.03 mm in *y* axis direction and returned back every 0.02 mm *x* axis-wise up to the complete closing.

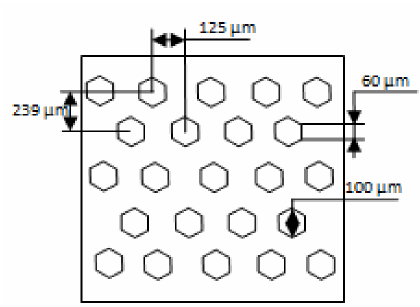

Fig. 9. The plate design

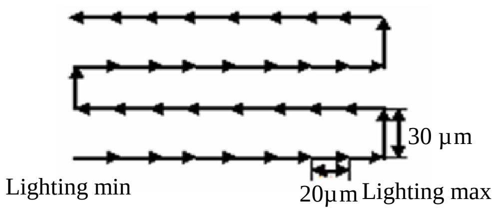

Fig. 10. The plate movement trajectory

Four steps in *y* axis direction were performed in analogous way. The diagram in Fig. 11 shows that membrane permeability parameters of the first and the fourth steps performed *y* axis-wise matched. The same effect was noticed during the second and the third steps.

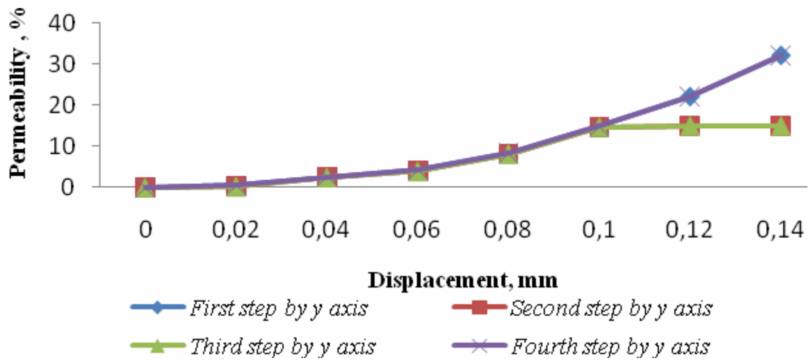

Fig. 11. Membrane permeability dependence on plate displacement

In order to check the obtained results, the authors performed analogous experimental research. Before the experimental studies of membrane light flow throughput, it was necessary to determine the dependence of photodiode electrical conductivity on the illumination level.

The experiment was carried out on a stand, which consists of a light source and its control unit, photodiode OP905, multimeter Mastech 8218 and a device for measuring environmental parameters (Velleman DVM 401 EnviromentMeter, illumination: the scale 20, 200, 2000, 20000 Lux, Resolution 0.1 Lux).

The experiment was performed in order to determine throughput of light intensity through the membrane when one of the plates performs linear motion in *x* and *y* axes. The setup illustrated in Fig. 12 was used. It consists of controlled intensity light source, the membrane (the two steel plates with pores of 100 µm diameter equally located), OP905 photodiode, multimeter.

During the experiment, one of the two membrane plates were tightly fixed, the other - a mobile plate is mounted on a micrometric displacement actuators, which can provide a linear movement of the mobile plate in direction of *x* and *y* axes.

The experiment was started by finding the point where the lighting is minimal (photodiode meter at that point recorded the lowest voltage), one of the plates has been moved in steps by following a path which is shown in Fig. 10 every 20 µm in *x* axis and going up to the highest point of enlightenment.

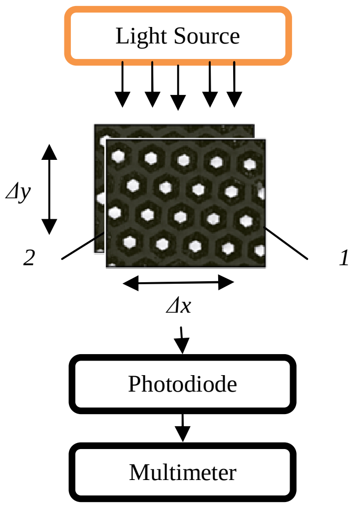

Fig. 12. Experimental stand of the luminous flux measurement: a) membrane consist of the plates having many hexagonal micro pores are located in shifted rectangular array of nodes: 1 - mobile plate, 2 - stationary plate

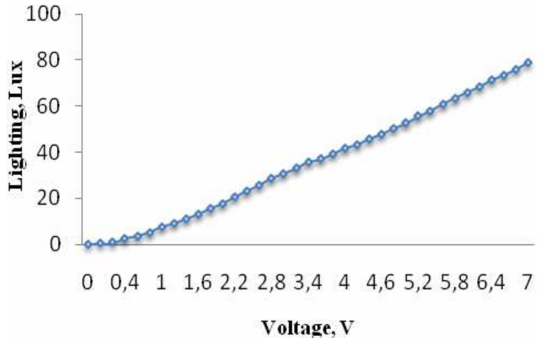

Fig. 13. Dependence of lighting on photodiode voltage

After founding the highest point of lighting the plate was moved in direction of *y* axis of 30 µm and the experiment was repeated (four times). The experiment was conducted at two different levels of lighting and the obtained results were similar.

The dependence in Fig. 14 indicates that the illumination of the first and the fourth step at *y* axis is received the same, therefore can be said that the illuminance was measured in all the intermediate positions between the plates and returned to a position, which corresponds to the original. In these dependences illumination is expressed in Lux from using the photodiode calibration dependence (Fig. 13).

The comparison of measured and simulated dependences reveals that the results are similar. Then, the simulation produced a maximum throughput of the membrane; the experiment reveals the maximum light throughput. However, the discrepancy has been observed and the simulation of a complete closure of the membrane to the opening was carried out in 7 steps of 0.02 mm, while the experimental maximum illuminance reached over nine steps. This can be explained by the fact that the experiment did not exactly find the lowest initial membrane flux flow throughput point. It is also necessary to take into account the manufacturing technology inaccuracies of plates.

Light flow intensity characteristics were measured in addition when the mobile plate is fixed to elastic link of piezoelectric actuators (Fig. 3). Equipment used in the experiment is shown in

Fig. 4. The measurement data collected and processed with LabView using the developed specific program allows to establish the experimental light intensity characteristics throughput through the membrane.

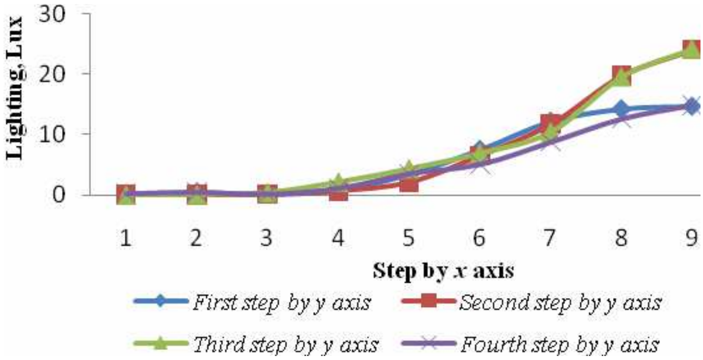

Fig. 14. Lighting dependence on the steps in *x* axis, when the maximum level of illuminance – 25 Lux

In this experiment, by changing the excitation frequency of piezoactuator was received the lighting by photodiode light level meter for the frequency range from 0 to 900 Hz, and maintaining a constant supply voltage of 70 V. These characteristics were recorded with a program built in LabView. Photodiode calibration dependence (Fig. 13) was used to obtain the dependence of lighting versus the excitation frequency of the piezoactuator (Fig. 15).

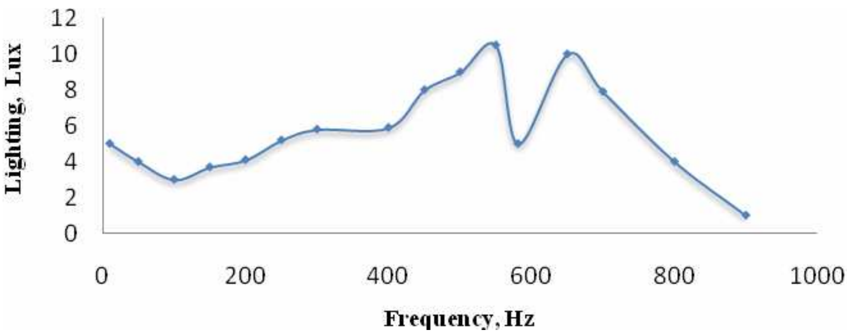

Fig. 15. Dependence of lighting versus the excitation frequency of the piezoactuator

In the lighting dependence (Fig. 15) significant light level changes were obtained in resonant frequency zone of the piezoactuator (Fig. 6), which triggers by the large shift of a mobile plate, and it exceeds 2 to 2.5 times the diameter of pores in the plate, which is equal to 100 µm.

Conclusions

1. The design of fast response time and precise control of laser beam light intensity control equipment with piezoelectric actuator and special light transmission membrane with micro pores was developed and presented.
2. The analysis of industrial piezoelectric actuators was performed and revealed that controlled-buckle type translation amplification mechanism is mostly suitable for the performance of linear positioning motion of the membrane plates with micro pores for the light intensity control equipment.
3. A dynamic characteristic of piezoelectric actuator with controlled-buckle type displacement amplification mechanism was defined. The research indicates that such actuator is suitable since

they are sufficiently fast in performance, are able to modulate light intensity in a range of frequencies of 0-700 Hz, and generate at least 100 μm translation motions, which is necessary in order to ensure complete light blocking and transmission.

4. By means of empirical simulation, the author identified the effusion of 0-32 percent in a membrane of laser beam light intensity control equipment during a linear motion of a plate with micro holes.

5. The results of light transmission through the membrane confirmed theoretical analysis. It was determined that such positions of a membrane where the simulation identified maximal and minimal transmission, experimentally indicated maximal and minimal transmission of a light intensity.

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