Mesh distribution of laser energy on the photosensitive surface of CCD

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Abstract: The mesh distribution of laser energy and crosstalk points on the photosensitive surface of visible array CCD was observed when it was irradiated by 1 064 nm pulsed laser from a distance of 30 m. It was found that the pitch of adjacent lattice was about 100 μm and remained unchanged as the incident laser energy increased or *F*-number of the front optical system decreased, but the center main spot and the spots at the ambient lattices could enlarge little by little with the decrease of *F*-number. It was clearly seen that every spot at the ambient lattices was geometric image of optical system′s stop when *F*-number is 2.8. There is no doubt that the novel phenomena are firstly reported and the related research will certainly promote deep investigation on the laser propagation in the optical system and the interaction between laser and material.

Key words: mesh distribution of laser energy; CCD; *F*-number; laser
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CCD 光敏面上激光能量的网状分布

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摘　要:采用波长为 1 064 nm 的脉冲激光从 30 m 的距离辐照可见光面阵 CCD 时,在 CCD 光敏面上观察到了激光能量和串扰点的网状分布。发现相邻格点的间距约为 100 μm,并且该间距在增大入射激光能量和减小前置光学系统 *F* 数的过程中保持不变,但是激光中心主光斑和周围格点处的小光斑随着 *F* 数的减小而逐渐增大。当 *F* 数为 2.8 时,可以清晰看到周围格点上的每一个光斑都是光学系统光阑的几何像。这一现象的相关研究将促进激光在光学系统中传输以及激光与物质相互作用等方面的深入研究。

关键词:激光能量的网状分布; CCD; *F* 数; 激光

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0 Introduction

CCD (Charge-Coupled Device) was firstly brought forward by W. S .Boyle and G. E. Smith from American Bell Laboratory in 1969 [1], and was designed successfully in 1970[2]. Owing to its low loss, high sensitivity and dynamic range, CCD has been widely used in many fields such as industry, agriculture, scientific research, national defense, etc[3-5]. However, everything has two sides, due to the characteristic of high sensitivity, CCD can be easily jammed or damaged by high power laser[6-8].

In recent years, there have been a large number of literatures and works that reported the research progress and results on the disturbing effect of CCD by laser irradiation. They mainly concentrate on four aspects as follows. The first one is to observe and discover the new phenomena [6,9-12] under different laser incident parameters, such as saturation, excessive saturation, crosstalk and optical breakdown; the second one is to measure and theoretically reckon the corresponding threshold when the above phenomena come forth[6,9,11]; the third one is to analyze the formation mechanism of new phenomena based on laser propagation theory and the interaction between laser and material [3,8]; the last one is to propose the new method or arithmetic and evaluate the laser disturbing effect [9,13-14]. The above works mainly investigated the laser disturbing effect in optical laboratory. The distance between laser and CCD is less than 10 m. However, there has been little investigation on laser disturbing effect from the long distance, owing to the influence of outside stray light and the limitation of laboratory size.

Fortunately, there is an optical darkroom in our center. It is 32 m (L) ×24 m (W) ×17 m(H) meter and is the largest optical darkroom in Asia. Its ground, wall and roof were all wiped with the extinction paint. So this darkroom can overcome the two above difficulties and provide a purely dark and large enough environment. We can increase the distance of laser and CCD to 30 m and effectively avoid the influence of outside light source, such as sun, moon, and lamp. The mesh distribution of laser energy on the photosensitive surface of CCD was surprisingly observed with the increase of incident laser energy. Moreover, the pitch of adjacent lattice is about 100 μm and remained unchanged as the incident laser energy increased or F-number of the front optical system decreased. It is undoubted that the novel phenomenon is found and reported for the first time.

1 Experimental scheme

Figure 1 shows the experimental layout that visible array CCD is irradiated by laser from a distance of 30 m. Laser is a nanosecond pulse Nd: YAG laser with electro-optic Q-switched and emits the laser at the wavelength of 1 064 nm. It is made in Beijing LABest Optronics Limited Corporation. Its launch parameters are as follows The energy of single pulse is 180 mJ, the repetition frequency can be respectively set as 10, 50, 100 Hz, and the beam divergence angle is about 0.5 mrad. Attenuator is the attenuation slices used for 1 064 nm laser. It has two functions which are effectively regulating the energy of incident laser at CCD and avoiding CCD damage by high power laser. The dashed line with the arrow represents the direction of laser transmission. 3 514 mm lens is the front optical system companied with CCD. It can project the scenery in the field of view on the photosensitive surface of CCD. Its main parameters are as follows. Its whole field of view is about 7.85°, the focal length is 35 mm and F-number (the radio of focal length and entrance pupil′s diameter) can be respectively set as 32, 16, 8, 4, 2.8.

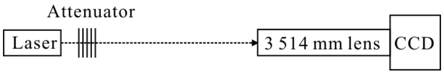


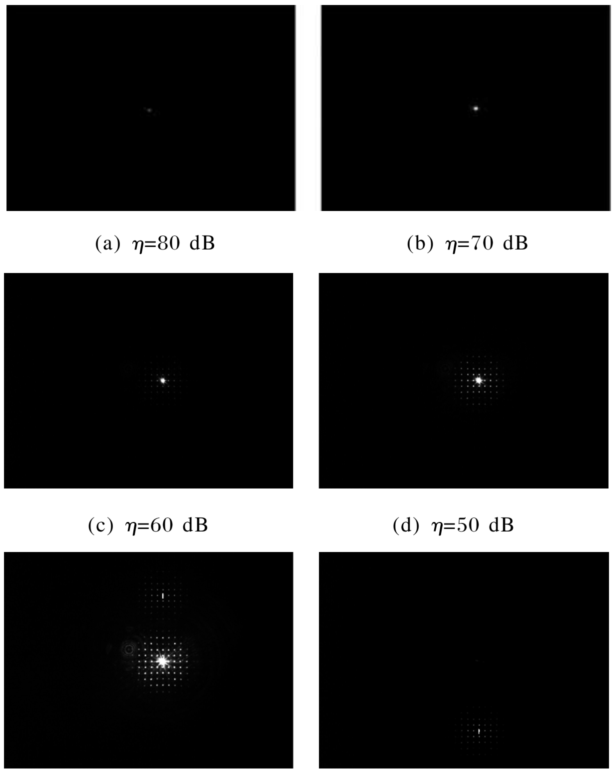
Fig.1 Experimental layout

The visible array CCD in the experimental layout is a monochromatic CCD marked in M23G445, which is made in Beijing United Scientific Camera & Imaging Corporation. It uses Sony′s chip named as ICX445AQA. Its other parameters include that the diagonal length is 1/3 inch (1 inch =2.54 cm), the pixel size is 3.75 μm×3.75 μm, the pixel number is 960 (H)×1 280 (V), the area of photosensitive surface is 4.8 mm×3.6 mm, the minimum radiation is 0.05 lx and the gray level of output image is from 1 to 4 096.

2 Experimental results and analysis

In order to avoid CCD damage by high power laser, the experiment starts with the high attenuation factor of 100 dB. The repetition frequency of incident pulse is set as 10 Hz. The integral time of CCD is adjusted as 40 ms. The F-number of 3 514 mm lens is 16. We observed the experimental phenomena as the laser energy at CCD gradually increased by decreasing the attenuation factor η. The whole experimental process is shown in Fig.2.

The laser spot appeared and it is very weak on the photosensitive surface when the attenuation factor decreased to 80 dB in Fig.2 (a), and the maximum gray level of output image is 1 658. The attenuation factor η decreases to 70 dB, the laser spot is getting bright and there are 8 saturated pixels whose gray level has reached 4 096 in Fig.2(b). When the attenuation factor η is 60 dB, the area of laser spot continues to increase and the number of saturated pixels increases to 60, at the same time, lattice array begins to come up around the laser spot in Fig.2 (c). When the attenuation factor η decrease to 50 dB, the area of laser spot continues to enlarge and the number of saturated pixels increases to 181, the range of lattice array spreads and the number of bright lattice increases, they are presented in the hexagonal structure in Fig.2(d). The attenuation factor η decrease to 45 dB in Fig.2(e), the area of laser spot continues to enlarge and the number of saturated pixels increases to 642, the divergent radiances come into being and they are very distinct around the laser spot, these radiances has been proved to be caused by the diffraction effect of the front optical system[15,16], the range of lattice array continues to spread, moreover, crosstalk points also present in the lattice array interestingly. We can observe the circular fringes at top left corner of lattice array in Fig.2 (e), and these fringes are caused by the interference effect of different reflective light [17,18]. Although the laser spot has disappeared, lattice array of crosstalk points exists in Fig.2(f).



(a) η=80 dB (b) η=70 dB

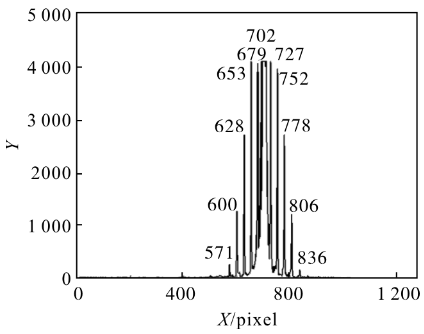
(c) η=60 dB (d) η=50 dB

(e) η=45 dB (f) η=45 dB

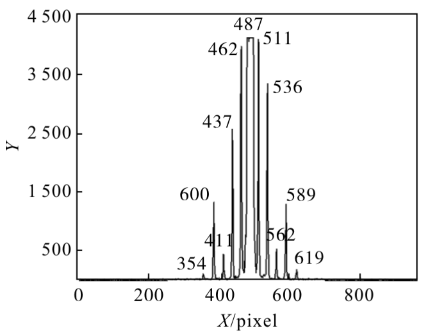
Fig.2 Laser energy distribution under different incident energy

In order to analyze the mesh distribution of laser energy and crosstalk points on the photosensitive surface, we take Fig.2(d) as an example. First of all, we read the image gray distribution of Fig.2(d) from CCD's digital output, and judge the center of laser spot at the pixel of (487,702) based on the gray level. Secondly, we investigate the variation of gray level in central line and analyze its rule, so we respectively draw the variable curves of the 487th line and the 702th row's gray level with pixel location, which correspond to Fig.3(a) and Fig.3(b). The extreme points are separately located at the pixel of 571, 600, 628, 653, 679, 702, 727, 752, 778, 806, and 836 in the 487th line, which are marked in Fig.3(a). The mean pitch of adjacent extreme point is calculated as 26.5 pixel. The pixel size is 3.75 μm×3.75 μm, so the mean pitch is about 100 μm. The analysis is similar in Fig.3(b). The extreme points are separately located at the pixel of 354, 384, 411, 437, 462, 487, 511, 536, 562, 589 and 619 in the 702th row, which are marked in Fig.3 (b). The mean pitch of adjacent extreme point is calculated as 26.5 pixel and about 100 μm. We study the distribution of lattice array in Fig.2(e) with the same method and find out that the increase of incident energy has no influence on the pitch of adjacent extreme point.

Crosstalk points also present in the lattice array in Fig.2(e) and Fig.2(f), therefore we need to investigate their distribution rule. We take Fig.2(f) as an example and judge the center of these points at the pixel of (790, 702). The variable curves of the 790th line and the 702th row's gray level are respectively drawn with pixel location in Fig.4(a) and Fig.4(b). The extreme points are separately located at the pixel of 601, 628, 654, 678, 702, 727, 753, 778 and 806 in the 790th line, which are marked in Fig.4(a) and almost coincide with the location of extreme points in the 487th line. The mean pitch of adjacent extreme point is calculated as 26.5 pixel and about 100 μm. The

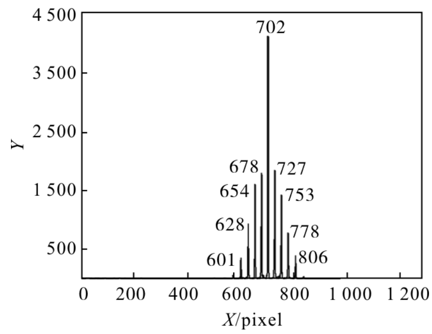


(a) Variation of gray level in the 487th line

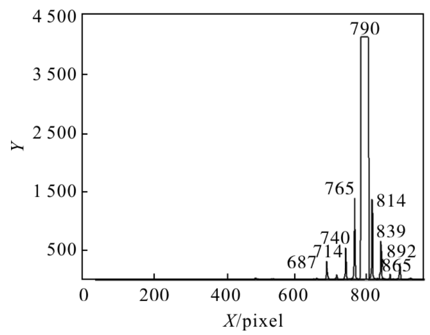


(b) Variation of gray level in the 702th row

Fig.3 Variable curves of gray level with pixel location in the central line



(a) Variation of gray level in the 790th line



(b) Variation of gray level in the 702th row

Fig.4 Gray distribution of crosstalk points with pixel location extreme points are separately located at the pixel of 687, 714, 740, 765, 790, 814, 839, 865 and 892 in the 790th line, which are marked in Fig.4(b). We calculate the mean pitch of adjacent extreme point is 26.5 pixel and about 100 μm.

We experimentally investigate the influence of optical system′s parameter on mesh distribution of laser distribution. 3 514 mm lens′ focal length is 35 mm and not adjustable, however, its *F* – number is adjustable and can be respectively set as 32, 16, 8, 4, 2.8. The repetitive frequency of laser pulse is set as 100 Hz and the attenuation factor η remains 60 dB.

The experimental phenomena are shown in Fig.5. When *F*–number is 32 in Fig.5 (a), the entrance pupil′ s diameter is minimal and the incident energy is least on the photosensitive surface. There is only a small laser spot in Fig.5(a). *F*–number decreases to 16 in Fig.5 (b), the laser spot begins to increase and lattice array comes into being. When *F*–number is 8 in Fig.5 (c), the laser spot continues to increase and the range of lattice array spreads, they also present in the hexagonal structure which is same with that in Fig.2 (d). *F*–number continues decreasing to 4 in Fig.5(d), the center laser spot and the spots at the ambient lattices can all enlarge, but the hexagonal structure remains unchanged. *F*–number is smallest as 2.8 in Fig.5 (e), the center laser spot and the spots at the ambient lattices continues to enlarge, we extract the range of the laser spot and zoom in Fig.5 (f). It is very distinct that the small spots at the ambient lattices are pentagon structure. 3 514 mm lens′stop is also pentagon structure, so we can deduce that these small spots are geometric image of optical system′ s stop. We calculate the mean pitch of adjacent lattice is 26.5 pixel and about 100 μm from Fig.5 (a) to Fig.5(f), corresponding to *F*=16, 8, 4, 2.8, 2.8. The pitch doesn′ t change with the decrease of *F*–number and the increase of incident laser energy.

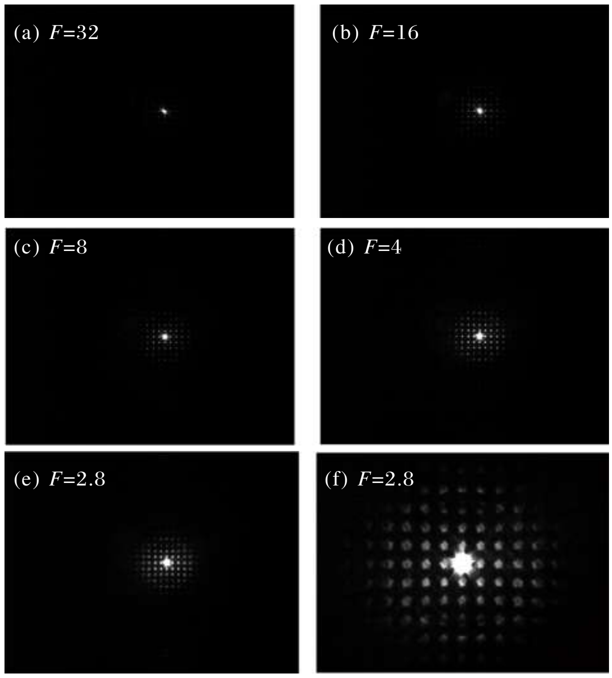


Fig.5 Laser energy distribution under different *F* number

We carry out the 1 064 nm laser disturbing experiment under different distances to analyze the mesh distribution. The experimental phenonmena are shown in Fig.6. The repetition frequency of incident pulse is set as 10 Hz. The integral time of CCD is adjusted as 40 ms. *F* – number of 3 514 mm lens is set as 16. The attenuation factor is adjusted as 50 dB. Figure6(a) displays the laser energy distribution on the photosensitive surface at the distance of 10 m. Compared with Fig.2(e), the central laser spot is bigger, the circular fringes at top left corner of lattice array is clearer, and the crosstalk line is a little wider. Figure 6(b), Fig.6(c) and Fig.6(d) separately show the laser energy distribution on the photosensitive surface at the distance of 15 m, 20 and 25 m. As we can see, the mesh distribution of laser energy always exists in the process of distance′ s variation. It needs to point out that owing to the limitation of optical darkroom′s size, we can′t carry out the laser disturbing experiment at farther distance.

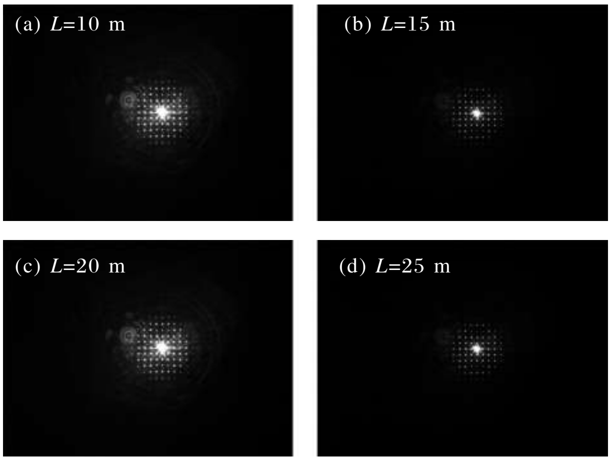


Fig.6 Energy distribution of 1 064 nm laser under different distances

In order to compare with the disturbing phenomena of 1 064 nm laser, we simultaneously do the experiment of 532 nm laser disturbing CCD. 532 nm laser is generated by frequency doubling of the above 1 064 nm laser, the beam divergence angle is about 3 mrad and the energy of single pulse is 50 mJ. The attenuation factor is adjusted as 60 dB. The all experimental phenonmena are shown in Fig.7. When the distance is 10 m, two crosstalk points appear up and down the laser spot in Fig.7(a). They are respectively located at the pixel of (717, 132) and (717, 723). We don′t do the disturbing experiment of higher laser energy to avoid destroying CCD. When the distance increases to 15 m, two crosstalk points still appear up and down the laser spot in Fig.7 (b). However, their position become the pixel of (717, 327) and (717, 918). The distance continues to increase to 20 m, there is only a crosstalk point down the laser spot which locates at the pixel of (717, 523) in Fig.7 (c). When the distance is 25 m, there is only a crosstalk point up the laser spot which locates at the pixel of (717, 169) in Fig.7(d). In a word, there is no mesh distribution of laser energy when 532 nm laser disturbs CCD. There are two reasons that this phenomena don′t exist in 532 nm laser′s experiment: the first one is that the operation wavelength of 3 514 mm lens is visible light range, most of 532 nm laser can transmit in 3 514 mm lens and the reflected light of lens surface is very little; the second one is that the spectral response of M23G445 CCD is also visible light range, most of 532 nm laser can be absorbed and the reflected light from the photosensitive surface of CCD is also very little, there are not other laser components, so it is very difficult to generate the interference effect of different laser components.

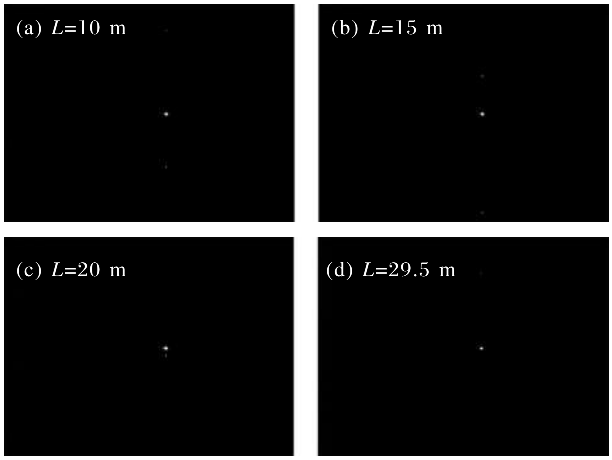


Fig.7 Energy distribution of 532 nm laser under different distances

3 Conclusion

We have reported the mesh distribution of laser energy and crosstalk points on the photosensitive surface of visible array CCD when it is irradiated by 1 064 nm pulsed laser from a distance of 30 m. The pitch of adjacent lattice is about 100 μm by calculating the extreme points in the central line and doesn′t change with the incease of incident laser energy, the decrease of *F* -number of the front optical system or the increase of distance. It is interesting that the novel phenomena just exist in the experiment of 1 064 nm laser disturbance, and doesn′t appear in the experiment of 532 nm laser disturbance.

In the future we will investigate the potential mechanism of novel phenomena from two aspects. On one hand, the research will focus on the front optical system, it generates many kinds of reflective light when laser propagates in optical system, some of them come from lens′ reflection, others caused by the detector′s reflection. These reflective lights interact and produce the interference effect on the photosensitive surface, it is maybe an important reason to generate lattice array; on the other hand, the research will concentrate on the interaction of laser and material, array CCD consists of many regular pixels, every pixel can be considered as a small and new light source in the range of laser irradiation, their interaction is also a possible reason. At last, we sincerely hope the related experts and scholars energetically participate in the research a potential mechanism and application of novel phenomena all over the world.

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