

## 改进胶囊内窥镜照明效果的研究

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**【摘要】**设计了一种具有大角度照明的胶囊内窥镜,通过特定的结构将中央的光能部分分布到周围出光角度大的照明区域,提高胶囊内窥镜的照明角度,满足其140°的视场角要求。应用3D结构设计软件Solidworks对特定的透明泡壳进行建模,光线追迹软件Tracepro进行光学仿真,分析了离光源不同位置的照度,结果表明此结构可以达到内窥镜对视场角140°的要求。

**【关键词】**胶囊内窥镜;视场角;照度;仿真

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## Design of a capsule endoscope with better illumination

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**Abstract:** A capsule endoscope with large illumination angles is designed to allow light energy at the center be mainly distributed into illuminated area with greater light-emitting angles through a specific structure, which enlarges the illumination angles and meets the requirement of a field of view of 140°. The light-transmitting bulb shell was modeled by 3D software Solidworks, and the optical simulation was achieved by ray tracing software Tracepro. The luminous intensity distributions at different distances from the light source were analyzed, and the results showed that the improved capsule endoscopy can realize a field of view of 140°.

**Keywords:** capsule endoscopy; angle of view; illumination; simulation

## 前言

胶囊内窥镜具有体积小、无疼痛、续航时间久等优势,被广泛应用于人体内部空间的观察<sup>[1-4]</sup>。LED光源具有节能、光谱范围广等优点,广泛应用于胶囊内窥镜<sup>[5-7]</sup>,但目前的LED光源发出的光存在照度不均匀,发散角度小等缺点<sup>[8-11]</sup>,当胶囊内窥镜采用LED做照明光源时,也会存在出光角度小的问题,无法满足内窥镜照明中对视场角140°的要求<sup>[12-13]</sup>,需要做特定的配光处理。目前,LED二次光学设计的方法主要有叠加法和剪裁法<sup>[14-15]</sup>。叠加法根据光源在空间的光强分布,使光线经过相应的光学系统后,光能量在目标面上重叠,由

于光学系统的对称性可以消除局部的不均匀性,从而达到目标面上的能量分布均匀以实现照明效果。如复眼透镜照明系统、LED阵列近场均匀照明系统等。剪裁法指已知光源的光强分布,设计相应的光学系统,使光源与目标面之间存在某种能量关系,以达到目标面上能量的均匀分布。剪裁法还包括 Simultaneous Multiple Surface(SMS)法、偏微分方程数值求解构建自由曲面法<sup>[16]</sup>、多参数优化法、网格划分法<sup>[17-20]</sup>等。本文利用光的折射原理,通过特定的结构把中央的光能部分分布到周围出光角度大的照明区域,提高胶囊内窥镜的照明角度,满足其140°的视场角要求。

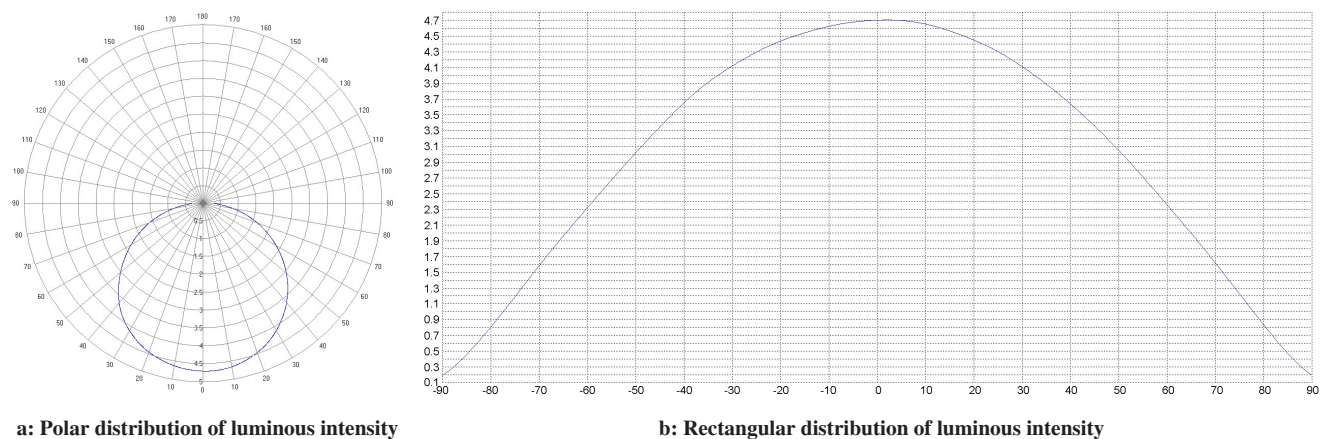
## 1 原理分析

通常的胶囊内窥镜采用LED作为照明光源,LED一般为朗伯型光源,其照射的光强于角度的余弦值,即: $I=I_0\cos\theta$ 。其中 $I$ 为角度为 $\theta$ 的光强, $I_0$ 为中心光强。如图1所示。

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a: Polar distribution of luminous intensity

b: Rectangular distribution of luminous intensity

图1 朗伯型光强分布图

Fig.1 Lambertian luminous intensity distribution

以光通量为15 lm光源为例,其中心光强约16 cd。一般的内窥镜其视场角为140°,而普通朗伯光源的发光角度为120°,无法满足内窥镜对视场角的要求。

一般的胶囊内窥镜3D结构如图2所示,主要由照明的LED发光光源、光学成像镜头、透光泡壳、控制电路等组成,把设计好的3D模型导入光学软件Tracepro进行光学仿真,光源为朗伯型发光,外罩为普通的透光聚合物材料,光学折射率为1.4左右,其出射光光强分布如图3所示。当照射到距离内窥镜为10、20、50、100 mm的目标接收面时,其原理示意图如图4所示,表面的照度分布如图5所示。

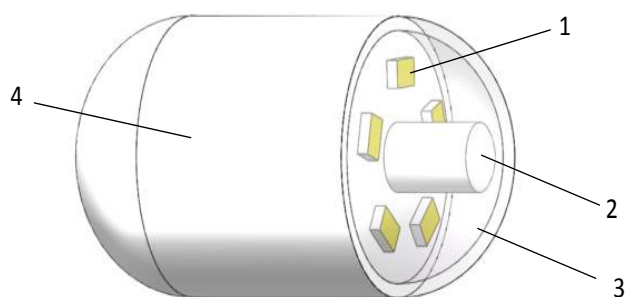
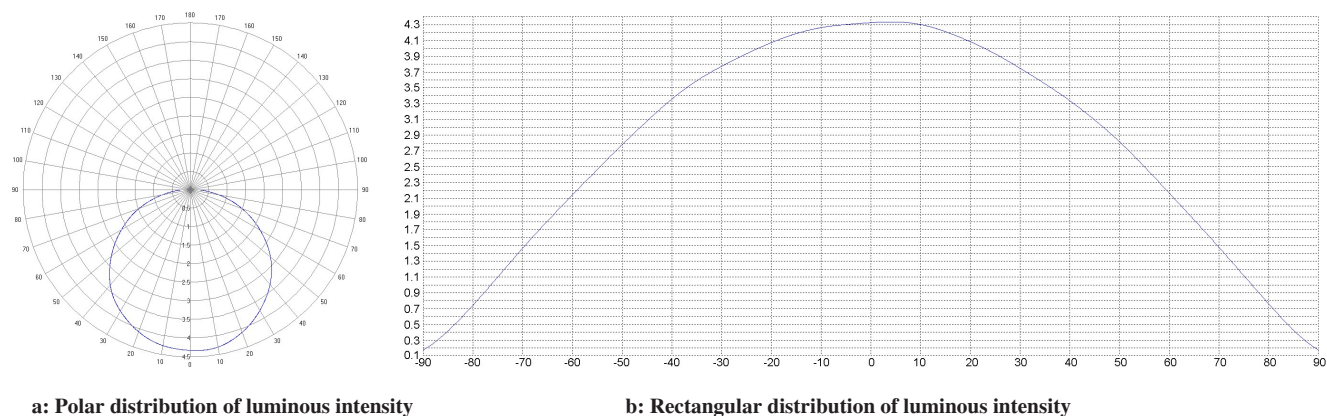


图2 胶囊内窥镜3D结构

Fig.2 Three-dimensional structure of capsule endoscope

1: LED light source; 2: Optical imaging lens; 3: Bubble shell; 4: Control circuit



a: Polar distribution of luminous intensity

b: Rectangular distribution of luminous intensity

图3 普通内窥镜光强分布图

Fig.3 Luminous intensity distribution of ordinary endoscope

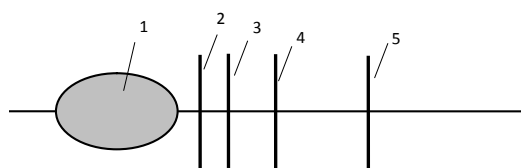
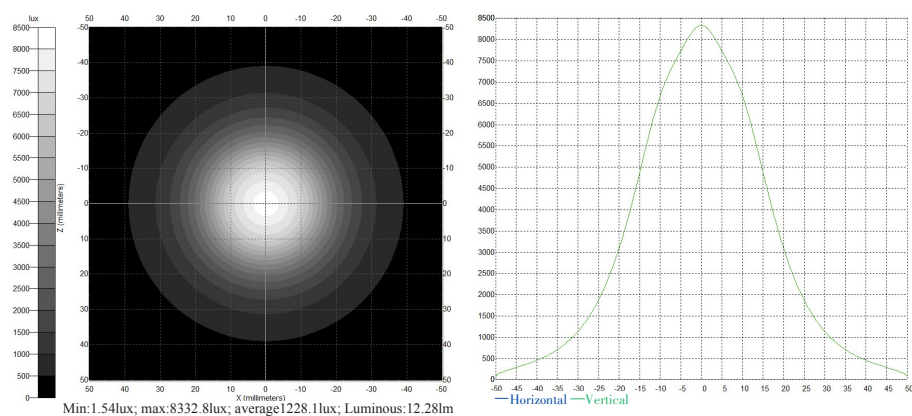


图4 目标接收面示意图

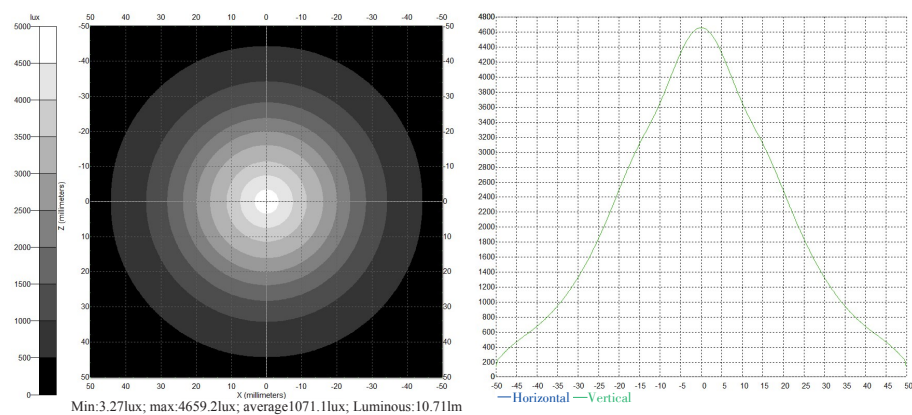
Fig.3 Diagram of target receiving surface

1: Capsule endoscope; 2: 10 mm receiving surface; 3: 20 mm receiving surface; 4: 50 mm receiving surface; 5: 100 mm receiving surface

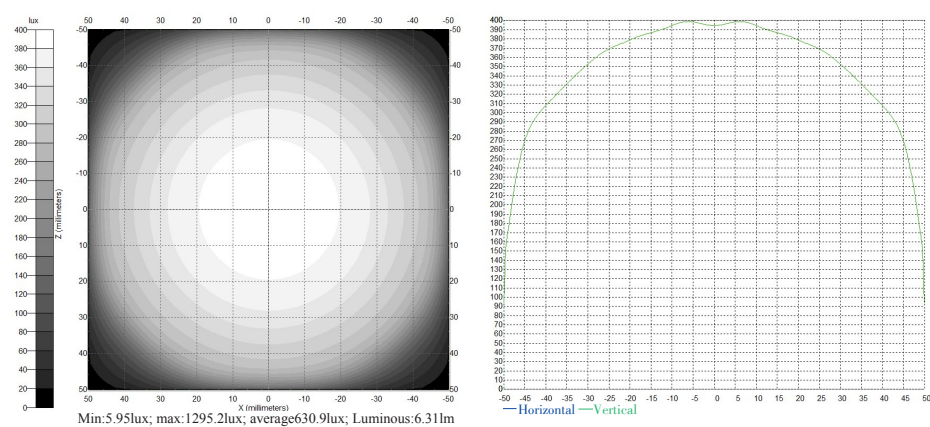
从图3中可以看出普通内窥镜的光强分布与朗伯型光强分布几乎一致,半强角为120°,其透光泡壳对光强分布几乎没有什么影响。从图5中可以看出随着目标接收面距离从10 mm变为100 mm时,接收面上的照度变得均匀,但中心照度较强。为了提高LED光源的发光角度,通过凹透镜的折射原理,让光能量分布到大角度照明区域,具体原理如图6所示。



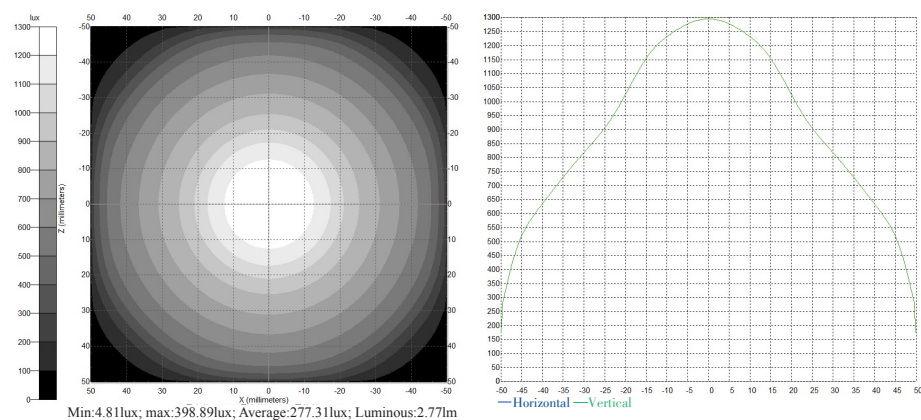
a: 10 mm receiving surface



b: 20 mm receiving surface



c: 50 mm receiving surface



d: 100 mm receiving surface

图5 普通光源不同距离目标接收面的照度分布图

Fig.5 Illumination distribution of ordinary endoscope on the target receiving surface at different distances from the light source



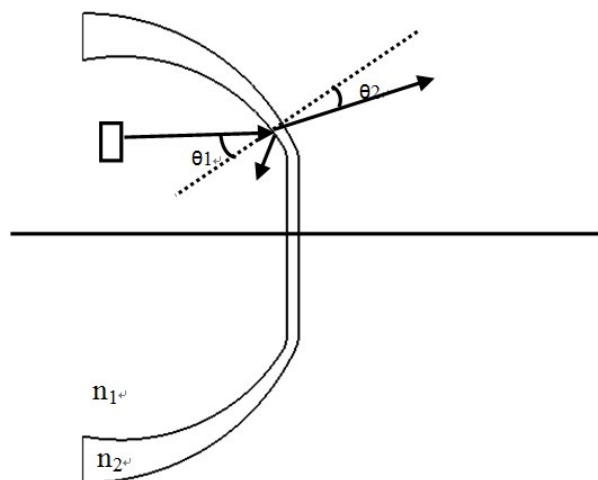


图6 光经环带微结构表面的光路示意图

Fig.6 Schematic diagram of the optical path of the light through the surface of the ring microstructure

当LED光源的出射光线到达环带微结构表面时,其反射光 $r$ 和折射光 $t$ 遵守菲涅尔定律:

$$r_s = \frac{n_1 \cos \theta_1 - n_2 \cos \theta_2}{n_1 \cos \theta_1 + n_2 \cos \theta_2} \quad (1)$$

$$t_s = \frac{2n_1 \cos \theta_1}{n_1 \cos \theta_1 + n_2 \cos \theta_2} \quad (2)$$

$$r_p = \frac{n_2 \cos \theta_1 - n_1 \cos \theta_2}{n_2 \cos \theta_1 + n_1 \cos \theta_2} \quad (3)$$

$$t_p = \frac{2n_1 \cos \theta_1}{n_2 \cos \theta_1 + n_1 \cos \theta_2} \quad (4)$$

其中 $n_1$ 为入射光所在介质的折射率, $n_2$ 为出射光线所在介质的折射率, $\theta_1$ 为入射角度, $\theta_2$ 为出射角度。

## 2 设计仿真及结果分析

应用3D建模软件Solidworks对上述的复眼结构的内窥镜进行建模。其具体结构如图7所示,为了不影响成像镜头的成像效果,在透光泡壳的顶部做成平面结构,光强分布如图8所示,目标接收面不同距离的照度如图9所示。

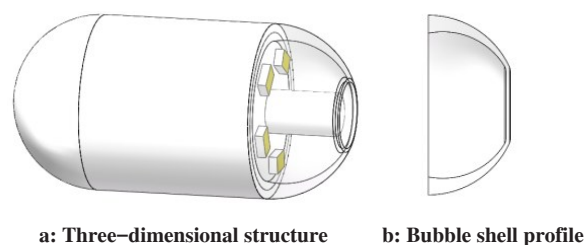


图7 凹透镜结构透光泡壳

Fig.7 Structure of concave lens and light-transmitting bulb

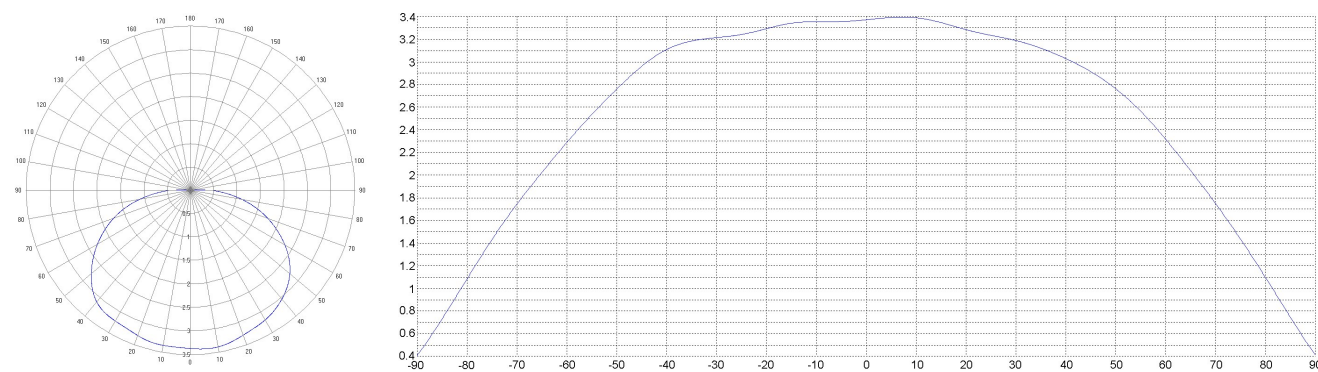


图8 改进后胶囊内窥镜光强分布图

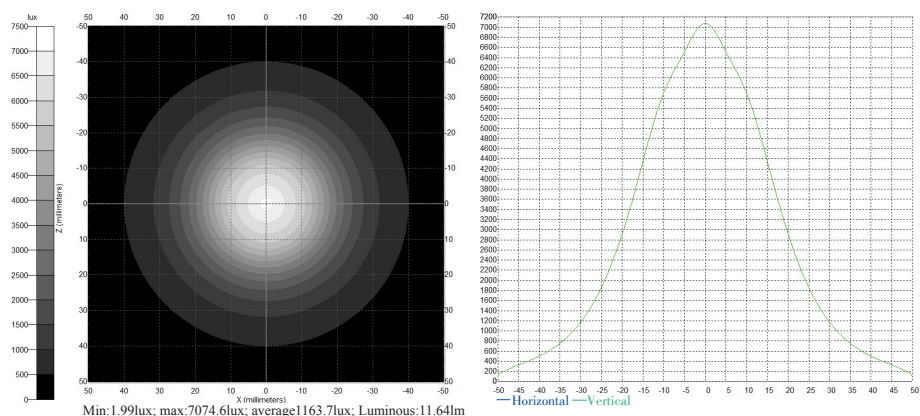
Fig.8 Luminous intensity distribution of improved capsule endoscope

从图8中可以看出改进后的凹透镜透光泡壳的胶囊内镜,其光强分布向旁边靠拢,半强角为 $140^\circ$ 左右,比普通的胶囊内镜的半强角增加 $20^\circ$ ,从而达到视场角的要求。

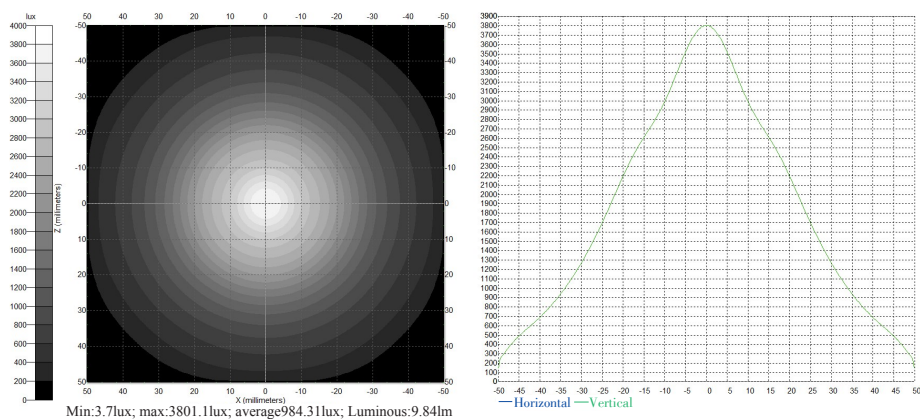
从图9中可以看出随着目标接收面距离从10 mm变为100 mm时,接收面上的照度变得均匀,各个位置的中心照度分别比图5的小:10 mm处减少1 000 lux;20 mm处减小1 000 lux;50 mm处减小200 lux;1 000 mm处减小80 lux。

## 3 总结

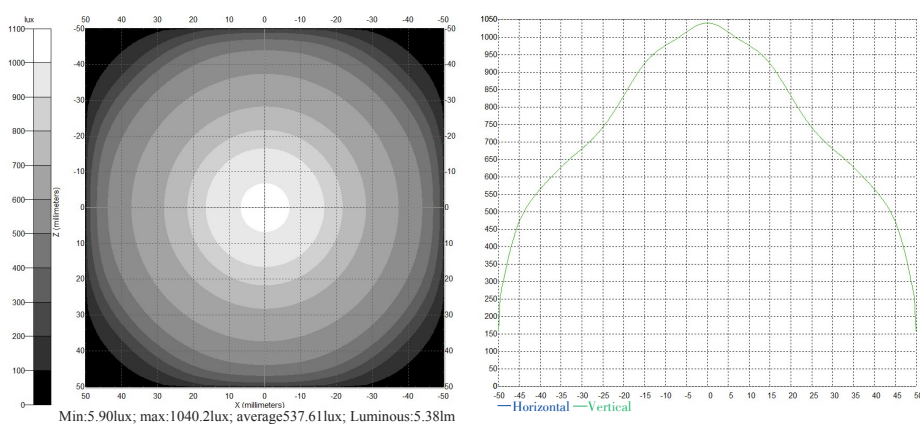
胶囊内窥镜广泛应用于人体内部空间的观察,但其应用朗伯型LED作为照明光源,存在发光角度小,无法满足内窥镜中对视场角 $140^\circ$ 的要求<sup>[12-13]</sup>,笔者应用3D建模软件Solidworks对上述的复眼结构的内窥镜进行建模设计了一凹透镜结构透光泡壳,把透光泡壳的顶部做成平面结构,改进后的凹透镜透光泡壳的胶囊内镜,半强角为 $140^\circ$ 左右,比普通的胶囊内镜的半强角增加 $20^\circ$ ,可以达到内窥镜对视场角 $140^\circ$ 的要求。



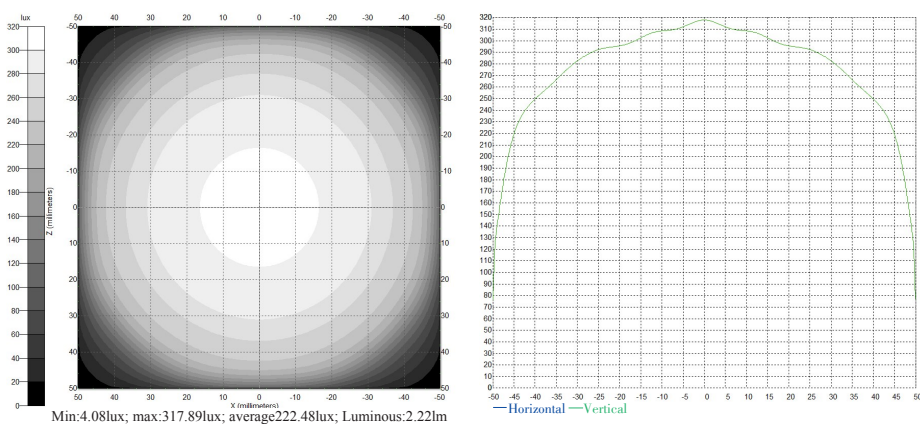
a: 10 mm receiving surface



b: 20 mm receiving surface



c: 50 mm receiving surface



d: 100 mm receiving surface

图9 改进后不同距离目标接收面的照度分布图

Fig.9 Illumination distribution of improved endoscope on the target receiving surface at different distances from the light source

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