minimum brightness level. A display having the desired structure has a relatively small aperture. In terms of image contrast, a display having a small aperture and inactive pixel areas covered by an absorbing material is exhibits better contrast performance than a with larger apertures. Small aperture displays work best, however, when the display material generates, passes or reflects sufficient light to meet the brightness requirements of the display device, and when the cover glass is thin compared to the aperture opening.

[0095] It is also possible to achieve these goals with a structure in which the aperture is small but the active area of the pixel is relatively large (e.g. approximately 50 percent). For tiled displays, it is desirable for the active pixel area to be small enough to allow vias to be formed in the inactive areas of the display. One method to achieve these goals is with a pixel structure that includes a lens structure which reflects or refracts light provided by the relatively large active pixel area and channels it through a relatively small aperture. As set forth above, it is desirable for the aperture of the display with the lenses to be less than or equal to 25 percent. The reflecting structures of the pixel may use refractive optics, refractive internal reflection, light piping, or surfaces coated with a reflective material. In an optimum configuration, the light provided by the active area of the pixel is reflected a minimal number of times but possibly multiple times, until it passes through the exit aperture. As set forth above, one negative artifact of the reduced size aperture is the increased visibility of individual pixels. The larger separation between adjacent pixels and the greater contrast in the display device make the individual pixels more visible. One way of hiding the pixel structure is to place a low reflectance diffusing or a diffracting surface (e.g. a spatial diffractive filter) in front of the viewer side of the front cover glass. This causes the active pixel areas to appear larger to the viewer.

[0096] One method by which the light provided by a relatively large active pixel area may be reduced to pass through a relatively small aperture is illustrated in **FIG. 19**. In this structure, lenses **1910** are formed on the viewer side of the front cover glass **120** and aligned with the emissive or light-valve portions **1912** of the pixels. As shown in **FIG. 19**, the area occupied by the active areas **1912** of the pixels is larger than the opening in the lens **1910** through which the light is emitted. Alternatively, for larger pixels, or for pixels arranged in a quad structure, such as is shown in **FIG. 8**, more than one lens may be formed for each pixel and placed as an array or as a random grouping in front of each pixel. This lens desirably has a clear aperture from which light provided by the active portion of the pixel is emitted to the viewer area. As described above, for maximum contrast, it is desirable for the size of this aperture to be as small as optics permit. The top surface **1914** of this aperture is desirably not planar so that specular reflective components are minimized. This surface may be convex, concave, or any shape desired. The sides of the lens structures are desirably reflective.

[0097] Reflectivity can be imparted to the walls of the lens structure **1910** either by selecting a material for the lens that has a refractive index that results in total internal reflectivity or by applying a reflective coating to the sides of the lens. The bottom surface of the lens (near to the active area **1912** of the pixel) is desirably as wide as possible so that as much light as possible enters the structure (e.g. the area of the bottom of the lens should approximate the size and shape as the active area of the pixel and positioned in close proximity to the active area). The area **1916** between the lenses on the viewer side is desirably filled with a light absorptive material to form a black matrix around the apertures in the lenses **1910**. This black matrix may fill the spaces or coat the surfaces between the sides of neighboring lens structures to conform to the sides between the lenses. In this configuration, there are no flat areas between the lenses that can result in a specular reflection. The black matrix fill which conforms to the side of the lens is shown in phantom in **FIG. 19** as **1917**. The refractive index of the black material is an important consideration. If the refractive index of this material is less than that of the lens, the light provided by the active pixel element may not be totally internally reflected and, thus, may be absorbed by the black material. This may be prevented by selecting a black material which has an lower index of refraction or by pre-coating the black-matrix area with a material having a low index of refraction before applying the black material.

[0098] It is desired that any specular component of the ambient light landing on the black matrix on the sides of the lens be reflected at an angle such that it strikes the black matrix on a neighboring lens. Thus the structure **1917** forms a light trap for ambient light. The steeper the angles on the sides of the lenses the better is the light trapping. The strong light suppression achieved by the black matrix structure **1917** results from trapping the light. This structure is more effective than using materials which absorb the light, and the lack of any planer component of the surface greatly reduces any specular component for light reflected from the surface of the display device. Indeed, because of the light trapping, significant contrast enhancement occurs in a lens structure such as that shown in **FIG. 19** even without the black material in the areas **1916** between the lenses.

[0099] There is some fraction of the emitted light that is reflected by the lens structure back into the pixel rather than being emitted. This loss can be minimized, however, by having as reflective a pixel as possible, thus this light is reflected again and has another opportunity to be emitted. Some ambient light may land on the aperture and interfere with light that is emitted from the lens structure. This may occur, for example, when ambient light enters the lens and is returned to the viewer space after several reflections inside the lens structure. This effect may be reduced by coating the lens structure **1910** with a material (such as a color filter) that transmits the emitted light, but absorbs all other wavelengths or polarizations. Another improvement may be to coat the viewer side of the lens aperture with an antireflecting coating to suppress the small component that would otherwise be reflected from the small aperture area.

[0100] The lenses **1910** may be formed on the viewer surface of the cover plate **120** during the construction of the display device using any forming technique that is compatible with the display technology. Alternatively, they may be formed in a separate operation and then aligned with, and laminated to the display surface with an optical adhesive. The shape of the lens in the plane of the display surface can include both one dimensional (linear lenticular lenses), and two dimensional (discrete lens arrays). Two dimensional arrays provide the greatest contrast improvement. The sides of the lenses can be straight or curved (convex, concave or both). The aperture at the top of the lenses (viewer side) may