3d printed light pipes for advanced illumination

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Additive manufacturing is a promising fabrication method for optical components used for illumination tasks. Here we present different design approaches for 3D printed light pipes in order to generate a thin laser line, which is needed for optical metrology. Additionally we briefly discuss the needed rework of the printed light pipes and the propagation of light within the light pipes.

1 Introduction

Additive Manufacturing offers the opportunity to create individual and complex designs. For mechanical components, the additive manufacturing is already widespread. But also for optical components, the method offers new design possibilities. However, the method has also disadvantages. Firstly, the high surface roughness needs to be mentioned. This has the consequence that the printed components need to be reworked. Secondly additive manufactured components exhibit a strong volume scattering. The latter is for lighting tasks often uncritically [1-3], or might be even be desirable to created visual effects. But if light pipes should be used in the context of optical metrology (e.g. light section method or laser triangulation method), it would be helpful if a thin line could be generated using the light pipe.

In the following we discuss the additive manufacturing of light pipes and how they can be used in order to generate a thin line for structured illumination.

2 Fabrication

For the production of optical components, a Multijet Modeling System of Keyence (Keyence AgilIsta) is available. Thereby the layers are deposited based on piezo activated print heads [4]. Thereby the printer can deposit two materials: the building material and the support material. The latter is necessary to realize overhanging structures of the building material.

Fig. 1a) shows an example of a complex light pipe structure which can easily be realized with the aid of a 3D printing process.

The creation of the model is done using a CAD program. Afterwards the model is imported into an optic design software (e.g. LightTools or ZEMAX) and the optical effect is simulated. After completion of the design a STL file is exported and sent directly to the printer, which prints the component. Fig. 1b) shows the volume scattering within the component, which can be attributed to the layer by layer deposition and to inhomogeneities in the volume (for details see [5]). On the other hand, these scattering effects can also be used consciously for design purposes, e.g. to create wanted visual effects (Fig. 1c).

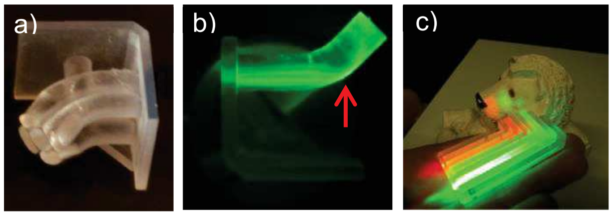

Fig. 1 *a) Example of a 3d printed complex light pipe design; b) demonstration of the volume scattering within a light pipe (incl. a clear scattering effect at the right / lower surface of the pipe – s. arrow); c) example of a light pipe design exhibiting extensive volume scattering in order to create design effects.*

3 Rework

As mentioned, the surface roughness of the printed components needs to be reworked, so that the components can be used for optical applications. To rework the parts robot polishing methods or coating methods can be used. They are described in detail elsewhere [5].

4 3D printed Light Pipes

In Fig. 2a) a printed light pipe is shown, which deflects light by 90°. This kind of light control would be, for example, desirable for the optical measurement of an undercut by means of laser triangulation. However, in this case light should be extracted from the light pipe as a very thin laser line. Fig. 2b) shows an illumination experiment. Here, the laser light is coupled into the light pipe from the upper / right corner (green arrow). At the lower left end light is coupled out. The obtained illumination is shown in Fig. 2c). It turns out that the original point-like laser beam fills the complete out coupling area (complete cross section of the light pipe) due to internal volume scattering. Thus an object would be illuminated by a broad diffuse spot, which is not wanted for metrology.

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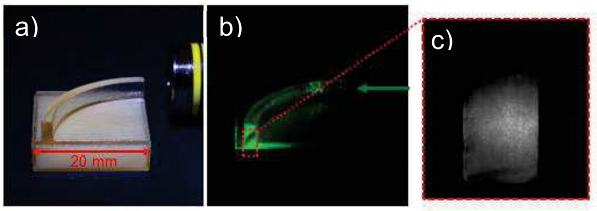

***Fig. 2** a) 3d printed 90° light pipe; b) illumination experiment; c) detected emitted light from the light pipe*

Fig. 3 shows a further variant of the 90° light pipe. Here, the light pipe is embedded into support material. Or in other words the light pipe from Fig. 2a is surrounded by support material during the printing process (s. Fig. 3a). Equivalent to Fig. 2b the lighting experiment was repeated. Now one can see that at the end of the light pipe, a thin laser line is coupled out, like it is needed for laser triangulation (s. Fig. 3c). Simulations show, that this effect is due to total internal reflections of the light rays at the left interface support material / building material. Stray light or scattered light, which leaves the light pipe (building material), is absorbed by the surrounding support material. Thus a thin line is generated finally.

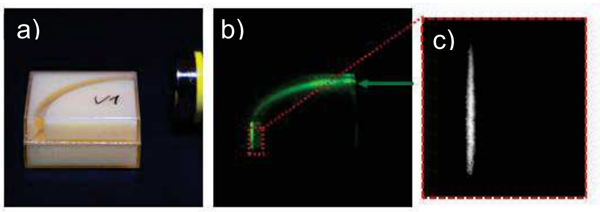

***Fig. 3** a) 3d printed light pipe surrounded by support material; b) illumination experiment; c) detected emitted light.*

Another way to generate a thin line is to use the intrinsic characteristics of the 3D printer. This is demonstrated in Fig. 4. Fig. 4a shows a 3d printed rectangular bar. This bar is illuminated from above (see red arrow) with a point-shaped laser. At the bottom a diffuse light spot is created (Fig. 4b). If one turns the bar by 90°, a completely different illumination structure is gained. The out coupled laser light shows a line like shape (s. Fig. 4d).

The expansion of a laser dot to a line would be expected, if one uses a cylindrical lens element. Since 3d printing is based on a layer by layer deposition, one could assume that this may lead to a wave like modulation of the side faces (Fig. 4a; or top and bottom surface in Fig. 4c). To verify this a white light interferometer (WLI) measurement of the side surfaces was performed (s. Fig. 4e). They show an arrangement of many "miniaturized" cylindrical lenses, which can be attributed to the deposited layers. The top and bottom surface does not show such regular structures, which is fine, as a diffuse spot was observed in this case.

The surface structured was recorded for both side surfaces of the complete bar and implemented as a real structure into the optical design software (see Fig. 5a). The result of this simulation is shown in Fig. 5b. It reveals a linear spreading of rays, like it was experimentally observed.

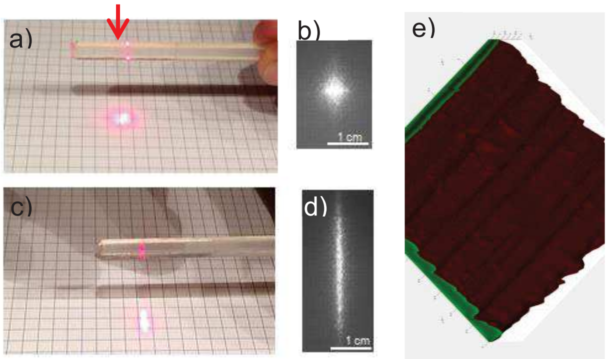

***Fig. 4** a) 3d printed bar illuminated from the top; b) resulting light distribution; c) bar rotated by 90°; d) resulting light distribution; e) WLI measurement of the surface*

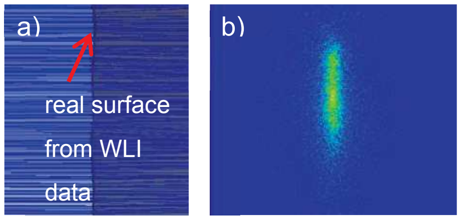

***Fig. 5** a) measured surface from Fig. 4e) included into the optic design of the bar (blue lines: rays); 5b) simulated light distribution (equivalent to the experiment)*

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