EFFECT OF ADDITIVE MANUFACTURED MICRO BEAM LENGTH ON DISPLACEMENT

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Abstract
In this study, fabrication and displacement analysis of the micro beam forming the basis of many micro-electro-mechanical system (MEMS) was performed. Micro beam fabricated using digital light processing (DLP), one of the additive manufacturing methods. An experimental setup was created to observe the displacement of the micro beam under 10V operating voltage. This voltage value was chosen because it is an optimum value for micro beam applications. For the characterization process, the micro beam connected to the probe station is connected to a circuit board with cables attached to the electrical pads. An optical microscope and a digital camera setup were used to observe displacements at the probe station. These displacements are determined by the image processing algorithm. In experimental studies, the displacements that occur by changing the length of the micro beam fabricated by the additive manufacturing method have been reported. A significant increase has been observed among the displacement data that occur in micro beams fabricated in four different lengths (100 µm, 150 µm, 300 µm, and 400 µm). As a result of the characterization processes, the highest displacement was 4.95 µm in the 400 µm length micro beam; the lowest displacement was measured as 1.39 µm in the 100 µm long micro beam. The displacement values for the micro beam lengths of 150 µm and 300 µm were measured as 2.32 µm and 4.15 µm, respectively. As a result, it has been observed that the change of micro beam length seriously affects the displacement properties.

Keywords: micro-electro-mechanical system, micro beam, characterization, image processing algorithm

INTRODUCTION

Microelectromechanical system (MEMS) is an integrated electromechanical system where the feature size and operating range of the components are on a micro-scale. Unlike traditional mechanical processing, the fabrication of the MEMS device uses semiconductor manufacturing, which includes surface micro processing and bulk micro processing, which can be compatible with an integrated circuit [1, 2]. These devices or systems have the ability to detect, control, activate, and create macro-scale effects. Many of the existing MEMS devices are electrostatic driven devices such as capacitive pressure sensors, drivers, micro pumps, RF switches, and vacuum resonators. Although microelectronic devices are solid and mechanically immovable, MEMS devices have moving 3D microstructures; micro consoles, micro actuators, micro beams, membranes, etc. [3-5]. In general, MEMS technology is used in automotive, biomedical, and, electric etc. [6, 7]. It offers low cost and high performance multifunction integrated devices for use in a wide range of consumer and industrial applications.

Additive manufacturing is a fabrication method that has enabled the easy production of miniaturized components. These components are used for building MEMS devices. This method is used to create parts from a computer-aided design (CAD) drawing where 3D models can be drawn in a virtual area followed by its printing through the layer-by-layer deposition of the constituent materials. One of the most important advantages of additive manufacturing is its ability to construct miniaturized structural geometries using simple steps that are not reachable by traditional subtractive fabrication methods. In recent years, 3D printing technology has made a significant advance in terms of innovation, leading to a paradigm shift from easy prototyping to mass fabrication, paving the path for MEMS device production using such methods [8, 9].

Micro beams are MEMS based systems with dimensions ranging from 1 μm to 1 mm. The application areas of these systems are gradually increasing and the technologies related to their construction are constantly developing. Micro beams are used as important components of structures such as many micro devices, and sensors [10, 11]. A current arises as a result of the application of electrical potential to the micro beam. When this current passes through the microstructure, it generates heat energy. This energy heats the structure and creates thermal stress. As a result, displacement occurs on the micro beam.

Fabrication of the designed micro beam was carried out by the digital light processing (DLP) method, one of the additive manufacturing techniques. DLP method using photocurable resins is attractive because it can be used to produce a single layer of the 3D object through spatially controlled solidification by using a projector light. This leads to the advantages of speed manufacturing, high resolution, and high surface quality. Besides, it is possible to tailor the final properties of the printed object by simply changing the photocurable resin formulations [12].

An experimental setup was created to observe the displacement of the different length micro beam under 10V operating voltage value. This voltage value was chosen because it is an optimum value for micro beam applications. Image processing algorithm has been developed for characterization processes. In the literature, sensor and camera systems, which are modules connected to probe stations, are used for the characterization processing of MEMS products [13, 14]. These systems are usually used to detect the motion of the products. In other words, we can say that the characterization process is performed with the hardware equipment. Because this equipment is expensive, it increases the cost of work. In this study, the displacement as a result of the voltage value applied to the micro beam was photographed, and the displacement of the beam according to the zero position was obtained with the image processing algorithm.

In this study, digital light processing, one of the additive manufacturing methods, was examined in detail, and micro beams of different lengths were fabricated using this method. An experimental setup was created to observe the displacement of the micro beams under constant operating voltage values. The displacement of the beam is determined by the image processing algorithm. As a result, it was observed that the change of micro beam length affects the displacement when a constant voltage is applied.

MATERIAL AND METHODS

Design Conditions

Thermal and electrical characterization of the 3D designed micro beam can be performed with a single model. The geometric structure of the designed micro beam is shown in Figure 1. Displacement by characterization is achieved by passing a current through the micro beam. Heat is generated as a result of the current flowing through the beam, and the increase in temperature causes displacement through thermal expansion. This allows the micro beam to move.

The micro beam is designed to move in one direction (y-axis). Characterization processes were carried out by applying DC voltage. For the displacement of the micro beam in the y-axis, the legs at both ends are connected to a substrate and voltage is applied. With the current and heat generated as a result of the applied voltage, the displacement of the micro beam in the y-axis is ensured.

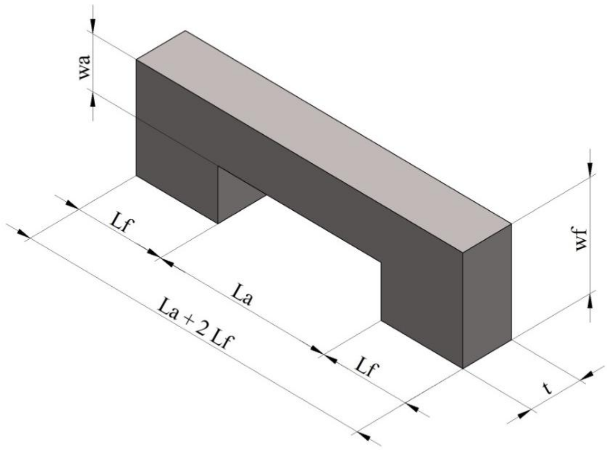

Fig. 1. *3D design of the micro beam*

The micro beam is designed in four different lengths: 100 μm, 150 μm, 300 μm, and 400 μm length. Various length displacement analyses of the micro beam were made with this design. All the dimensions of micro beam are shown in Table 1. These values were obtained with the measurements of the beam made with the DLP method. All of the designs and dimensions were made according to the specifications given in the design criteria. A photopolymer material is used in the fabrication of micro beam.

Table 1. Descriptions of micro beams designed in different lengths

Parameter (µm)	**Symbol**	**Micro Beam-1**	**Micro Beam-2**	**Micro Beam-3**	**Micro Beam-4**
Length of feet	f	25	25	25	25
Length of the arm	a	50	100	250	350
Height of the arm	w_a	25	25	25	25
Height of the feet	w_f	50	50	50	50
Thickness of the beam	t	30	30	30	30

Digital Light Processing

Digital light processing (DLP) is an additive manufacturing method that uses ultraviolet (UV) light to solidify a liquid photopolymer material. This method is widely used in 3D printing due to its high resolution, fast printing speed and simple structure. The working principle of DLP method is shown in Figure 2.

Before the writing process begins, the 3D CAD model of the object is first sliced into layers in a parallel plane (Figure 2). Each slice that comes out in the next step is transformed into a 2D mask image. A projection device is used to harden the resin in the tank. This device uses a digital masking method to reflect the mask image onto the resin surface. The 3D object is produced layer by layer in this system. Unlike other stereolithography (SLA) techniques that use different light sources, DLP technique uses an aerial light source to reflect the entire mask image at the same time. As a result, the fabrication process performed by the DLP method is faster than other 3D printer techniques.

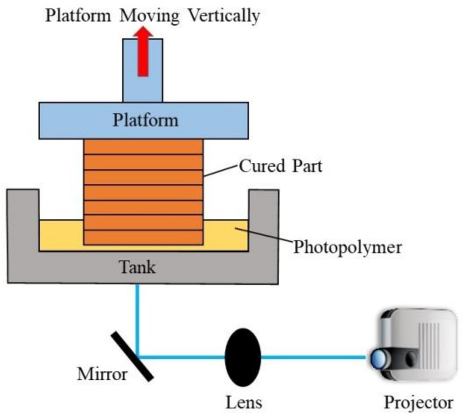

Fig. 2. *Schematic of the DLP printing system [15]*

In order to successfully solidify the liquid photopolymers used for the production of 3D material, the DLP method requires sufficient light intensity to the liquid surface. The projector used in this study is equipped to provide a 400 nm HD ultraviolet light source. Lenses are placed between the projector and the work surface to provide the light intensity. The XY resolution of the 3D printer used for DLP method is 65 µm and the maximum building size is 125x70x120 mm. In this case, the production of large models is difficult. As the masking method in our study, the projector uses the digital micro mirror device (DMD) method. An optical reflector is used to adjust the direction of UV light. An electrical position adjustment device is used to adjust the position of the reflector. The resin vat is with an optical quartz glass bottom and Aluminum frame. A flexible compressing device is used to press the resin vat. This device lets the vat be lifted at a specific height. The pressing force that the device enforces to the vat rises as the lifting height increases to refrain effect forces. The aluminum frame is used as a curing bed for the resin. For the DLP method, the material used in this study was the IP-S resin, which is a photopolymer.

RESULTS AND DISCUSSIONS

Fabrication

In this section, the micro beam, whose CAD model is given in Figure 1, was fabricated using 3D printing device. After the CAD model of the micro beam is sliced and transformed into mask images, the images are loaded into the printer. The printing process begins after the photopolymer material is poured into the resin vat. In the printing of the first layer, the platform is driven down to form a gap with the base of the resin tank. As this layer cures, the printing process is paused and the current position of the platform is recorded. The platform is then lifted up. After the zero position of the platform is recalibrated, the platform is placed on top of the last attempt to reduce the separation force and create a larger gap. The platform is driven closer to the bottom of the tank and the first layer is reprinted. After the first layer is printed successfully, the remaining layers are printed.

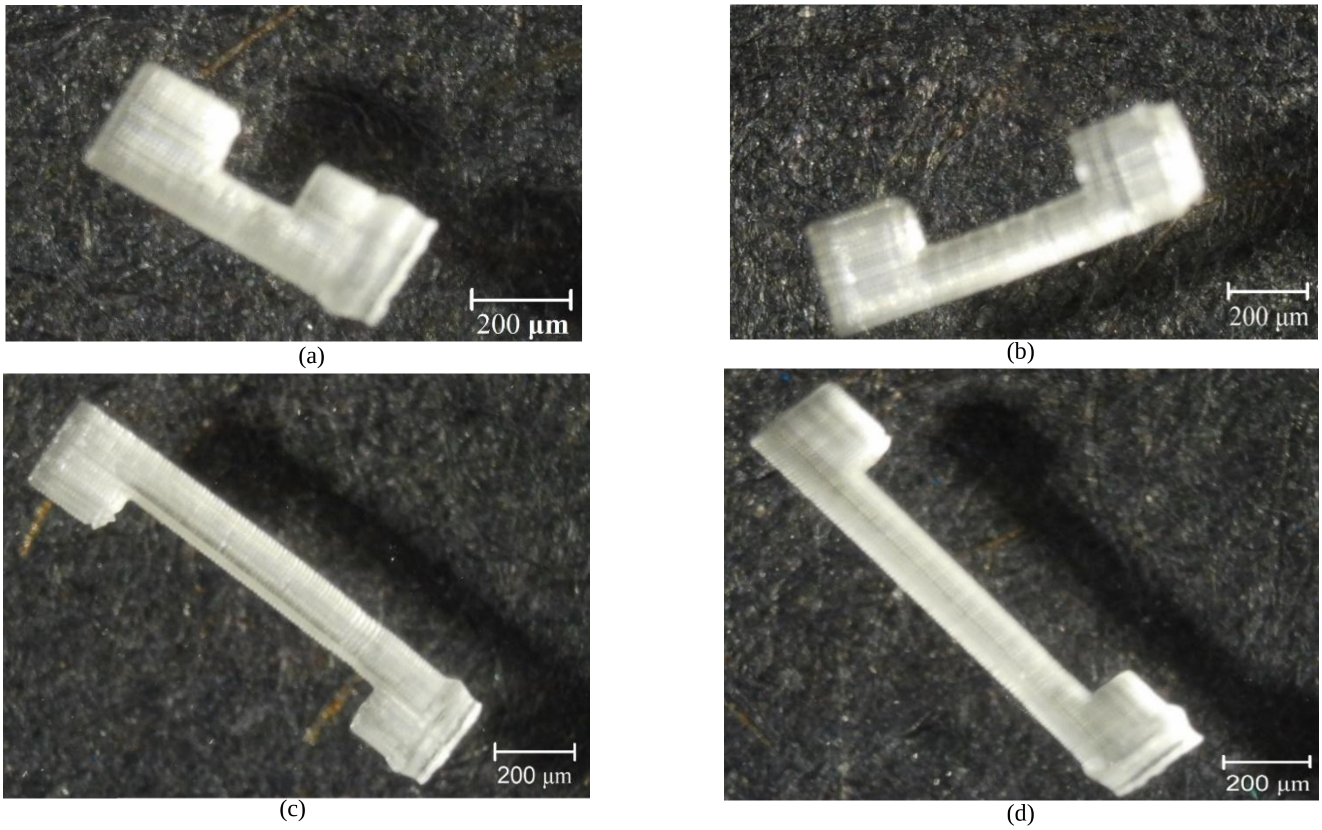

Fig. 3. *Images of the micro beams fabricated with the DLP method (a) fabrication of micro beam-1 (b) fabrication of micro beam-2 (c) fabrication of micro beam-3 (d) fabrication of micro beam-4*

Support structures are used in the 3D-model of micro beam. The number of supports used in the arms of the beam is 30, its diameter is 4 µm and the height is 5 µm. In cases where the number of supports in the arms is low, structural distortions occurred during the fabrication of the micro beam. The optimum support number for this application has been determined as above. These support structures allow the micro beam arms to be held together. The lack of supports causes structural defects in the beam. If the support structures are not fabricated correctly, it will cause deterioration and breakings in the micro beam. Images of the micro beams (micro beam-1, micro beam-2, micro beam-3, and micro beam-4) fabricated with the DLP are shown in Figure 3.

Characterization

An experimental setup was created to observe the displacement of the various length micro beam at 10V operating voltage value defined earlier. To characterize the displacement of micro beam in a probe station, an installation was used that included a 120x magnification optical microscope and a c mounting adapter for a digital camera. In this study, “Cascade Microtech PM5” was used as a probe station. In this study, “Cascade Microtech PM5” was used as a probe station. The micro beam connected to the probe station for the characterization process is attached to a circuit board with cables attached to the electrical pads. Besides, the device called “Keithley 2182A - Nano Voltmeter” was used as the voltage source to determine the current-voltage (I-V) properties of the micro beam. Electrical tests were carried out on the micro beams.

The operating voltage value for the micro beams were determined by 10V. This voltage value was chosen because it is an optimum value for micro beam applications. Observations of micro beam displacements were made using a video recording setup described hereinafter. Voltages above operating voltage value can cause the micro beam to melt and distortion.

The displacements of the micro beam are recorded as a video sequence at 2 fps. During the experimental studies, videos characterizing the displacements of the micro beam were obtained. The frames in these videos were analyzed using an image processing algorithm that measured the displacement of the micro beam between consecutive frames

According to this algorithm, the image before applying a voltage to the micro beam is taken as a reference. The operating voltage value is then applied to the micro beams. After voltage was applied, the images of the micro beams were taken. The images taken were compared with the reference images and analyzed by the image processing algorithm. As a result of the analysis, the displacements of the micro beams is detected.

For a clear understanding of this algorithm, the detection of displacement by applying 10V voltage to the 150 µm length micro beam-2 is described below with the image processing technique:

- First, the reference image was taken. The image before applying a voltage to the micro beam was taken as in Figure 4. This image was taken using a microscope.

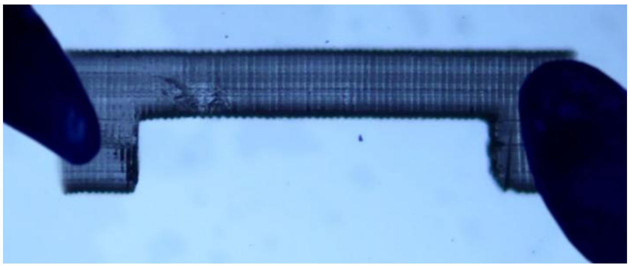

Fig. 4. *The reference image before applying voltage*

- Pixel and length calculations related to this image were made with MATLAB. Pixel calculation was obtained according to the length of the micro beam. These calculations were made according to the length of the arm of the micro beam. This arm length is 100 µm. The pixel value of this arm was calculated as 729 µm with image processing. We need to define the Pixel Micron Ratio (PMR). The PMR value is obtained as in Equation 1.

$$PMR = \frac{length\ of\ arm}{value\ of\ pixel} = \frac{100}{729} = 0.137$$
(1)

- After the calculations related to the reference image above, the image obtained by applying 10V voltage to the micro beam was transferred to the MATLAB program (Figure 5).

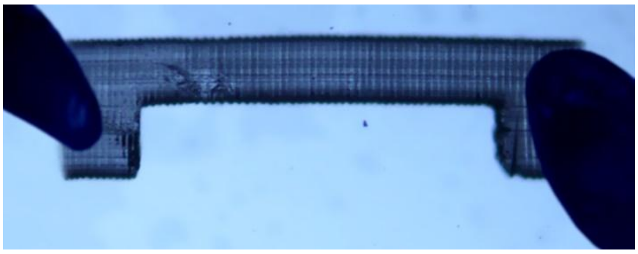

Fig. 5. *Image obtained when 10V voltage is applied to the micro beam*

- Figure 4 and Figure 5 must be combined to calculate the displacement of the micro beam. When these operations are done with image processing codes, the new image is acquired, as in Figure 6. Since it is important to displace the y-axis of the micro beam, the image has been enlarged with codes (Figure 7). If the corner points of the micro beam are looked at, the micron level displacement has emerged. It is necessary to measure how far the corner point of the micro beam goes in pixels on the y-axis to find this displacement. Two pointers are placed at the corner point for this measurement. The top pointer represents the reference image of the micro beam before applying voltage, and the bottom pointer represents the image after applying a voltage to the micro beam.

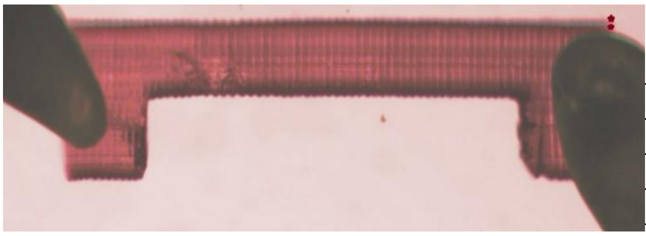

Fig. 6. *Combining of two image*

- This motion is obtained from the difference between two points' pixel change (PC) as in Equation 2.

$$PC = 225 - 208 = 17 \quad (2)$$

- Micro exchange (MC) value is obtained as in Equation 3:

$$MC = PC * PRO = 17 * 0.137 = 2.32\mu m \quad (3)$$

Fig. 7. *Zoomed form of two images*

After applying 10V voltage to the micro beam-2, the displacement was measured as 2.32 µm. When all these operations are done for each micro beams, displacement values are obtained as in Table 2. Characterization operations were carried out in the 10V voltage value at room temperature. When the values in Table 3 are examined, it has been observed that the change of micro beam length significantly affected the displacement data. Operating the micro beams close to the upper voltage can speed up system failure and increase the chances of wear and failure. Thus, the operating voltage can be determined according to the optimum voltage level between the lower and upper operating thresholds.

Table 2. Characterization results of the micro beams

	Length [µm]	**Displacement [µm]**
micro beam-1	100	1.39
micro beam-2	150	2.32
micro beam-3	300	4.15
micro beam-4	400	4.95

CONCLUSION

In this study, fabrication and displacement analysis of the micro beam forming, the basis of many microelectromechanical systems (MEMS) was performed. Micro beam fabricated using digital light processing (DLP), one of the additive manufacturing methods. This method is a common method used in 3D printer devices. In the fabrication of some CAD designs used in the manufacturing process, breaks and distortions occurred. This is due to the differences in support structures. The total number of supports on the arm of the fabricated micro beam was 30, and the distance between the two supports was adjusted as an average of 10-15 µm. Supports with a diameter of 4 µm are manufactured using the DLP method.

An experimental setup was created to observe the displacement of the micro beam under 10V operating voltage. This voltage value was chosen because it is an optimum value for micro beam applications. For the characterization process, the micro beam connected to the probe station is connected to a circuit board with cables attached to the electrical pads. An optical microscope and a digital camera setup were used to observe displacements at the probe station. The displacement of the micro beam was recorded as a sequence of images. Upon completion of the studies in the experimental design, pictures characterizing the micro beam displacement were obtained. The frames in the picture taken were analyzed using a special image processing algorithm that measures the displacement of the micro beam in MATLAB.

In experimental studies, the displacements that occur by changing the length of the micro beam fabricated by the additive manufacturing method have been reported. A significant increase has been observed among the displacement data that occur in micro beams fabricated in four different lengths (100 µm, 150 µm, 300 µm, and 400 µm). As a result of the characterization processes, the highest displacement was 4.95 µm in the 400 µm length micro beam; the lowest displacement was measured as 1.39 µm in a 100 µm length micro beam. The displacement values for the micro beam lengths of 150 µm and 300 µm were measured as 2.32 µm and 4.15 µm, respectively. As a result, it has been observed that the change of micro beam length seriously affects the displacement properties.

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