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On-demand-like FDM 3D printhead consideration

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Abstract

HIT Research Corp, the research and development arm of HIT Devices Ltd., has been studying the feasibility of utilizing the patented on-demand and temperature-controllable heating device for various applications. One field identified and focused has been the fast growing three dimensional (3D) printing technology. There are several different methods of 3D printing, but the technology compatible with our device and also most widely used process is known as Fused Deposition Modelling (FDM).

An FDM 3D printer uses a thermoplastic filament, which is heated to its melting point by a heating device and then extruded through a small hole, layer by layer, to create a three dimensional object. The traditional 3D extruder (or printhead as we refer to) heating section has a discrete heating element and temperature sensor which makes it large and bulky. We integrated them on a single ceramic substrate so it will be more efficient, compact, lighter and easier to maneuver for the three dimensional head movement.

Unlike many existing printheads which incorporate a substantial size cooling fan or some cooling devices in order to bleed off the excess heat which is not used for melting the material, the excess heat of the new heating head is minimal and cooling requirement is substantially reduced.

The most significant benefit for the new configuration is the ability to be made into a multi-nozzle line-type printhead due to the size and thermal efficiency. This will be left for the future report, the preliminary study indicates that there will be a serious impact on the process time when it becomes an actual product.

Study Scope and Goal

There are several vast different technologies in the 3D printer field. Since our interest is specifically on thermal-related field, we are limiting our study in extrusion of thermoplastic material, commonly known as Fused Deposition Modelling (FDM).

The goal of this paper is to study the new heating head which is efficient, compact and versatile for FDM 3D printer. The traditional heating heads are rather bulky and heavy as they are made with discrete components, such as the heaters, thermistors, in many cases, the cooling devices such as finned heatsinks and fan motors. They are continuously heated at a constant temperature.

The new printhead is smaller, lighter and thermally efficient. As a result, it can heat the material (filament) when it is needed similar to "on-demand" devices. Since it is smaller and lighter than the typical heating heads, the mechanical servo requirements for the head movements will be reduced greatly. Due to the new structure, the temperature can be precisely monitored and controlled. In addition, this on-demand-like heating characteristics can save energy, lower power drive and less likely to be health-hazardous. Also the heating head can be easily staggered as multiple-nozzle devices as discussed later. The heating elements are directly on the FDM material (filament) path which is suitable for some material which requires higher temperature than popular materials like ABS resin and PLA. Our ultimate goal is to reach the higher temperature range of 400 °C ~ 500 °C which will open up the possible development of new FDM materials which are not available currently, especially in higher durability.

The detail discussion of multi-nozzle line-type 3D printhead is reserved in the future discussion, there are multitude of new ideas and development work are pursued using the new printhead technology.

3D Printhead Defined

Since the term "printhead" in the FDM 3D environment has been referred to as "extruder" or "hot-end" sometimes, so it may be helpful to define what we call "printhead" in our paper. We define the printhead as the device which the thermoplastic filament is pushed in from one end, heated to the melting point and pushed out of the other end.

Figure 1 shows a typical printhead with the cooling fin and Figure 2 is a graphic illustration. The printhead we define is the inside content of the dotted line box. The components are a nozzle, heating element, temperature sensor and mounting block.

Usually the cooling device such as the heatsink with fins and often the cooling fun. We are not including the cooling device in our definition because of the reason discussed later part of the paper.

Figure 1
Picture of typical printhead on market

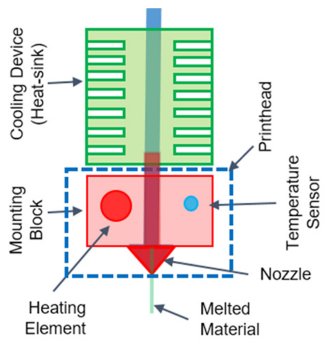

Figure 2
Graphic illustration printhead parts

New Printhead Concept

The new printhead is based on the concept which was developed by HIT Devices Ltd. of Kyoto, Japan. The ceramic substrate has integrated the heating element and temperature sensor element as shown on Figure 3.

The unique feature of ceramic substrate is that the actual heating is on the other side where the heating and sensor elements are placed. So, the heating surface is the back side of the heater/sensor side.

There are several benefits for this type of arrangement as follows:

- The heating element does not touch the media directly

- Because the heating surface is the backside of the ceramic substrate, there is no problem with abrasion, chemical and/or electrolysis
- Manufacturing process is simpler as the heater surface does not be needed to protected like the regular heating devices
- Heater/sensor can be fine-tuned, if needed after the oven-curing process is completed
- Heat spreads evenly over the ceramic substrate avoiding "hot spot"

The heater and sensor elements pattern is shown on Figure 3. The filament moves from top to bottom of the substrate and having multiple heating and temperature sensing elements can make the temperature radiance. Since the filament needs to be pushed out, keeping existing temperature higher than entering temperature helps the material movement.

The printhead is fabricated with a pair of ceramic substrates, the heating surfaces facing to each other and sandwiching the filament material as illustrated on Figure 4.

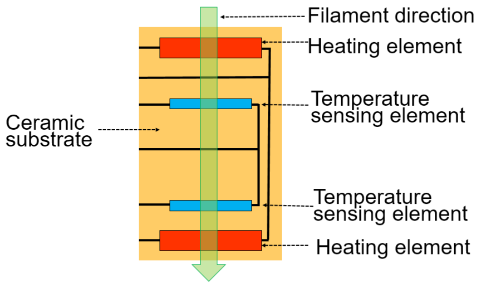

Figure 3
Key component of printhead (heating side of ceramic substrate)

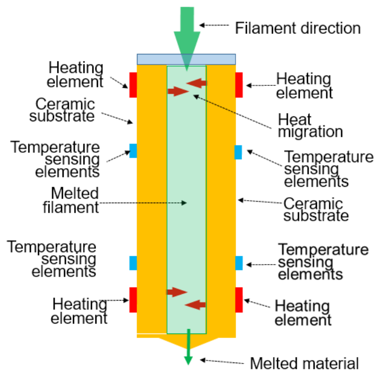

Figure 4
Illustration of new printhead assembly (side view)

Comparison with the Existing Printhead

Physical comparison of existing and new printhead shows there is a substantial reduction on size and weight.

The indirect factors, besides the obvious physical size and weight points, are significant reductions in such area as:

- Printhead driving energy
- Cooling system energy
- Moving printhead assembly
- Overall power consumption
- Temperature response time

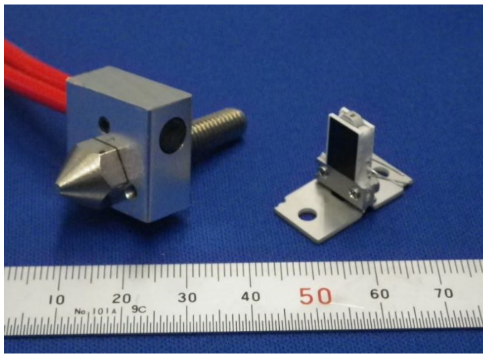

Figure 5
Comparison of existing and new printheads

List of objectively compared specification differences between the typical printhead existing on the market today and the newly developed head is as follows:

1. Integrated heating element and temperature sensor
2. Real-time temperature monitoring and controlling
3. Fast temperature rise time (seconds rather than minutes)
4. Extremely energy efficient performance
5. Heat-as-needed eliminates/reduces cooling device
6. Smaller in size and lighter in weight
7. Possible to make multiple-nozzle/line printhead

Each point is discussed separately.

Integrated heating element and temperature sensor

The most unique part of the new printhead is the integrated heating element and temperature sensor element on the ceramic substrate. The original idea was developed from the heating head used for thermal process in the plastic card industry where efficient and precisely-controlled temperature heating was required[1].

The temperature sensor element is made of resistive material which has the positive temperature coefficient of 1500 PPM/°C and it reacts to the change of temperature as the filament is fed through the printhead.

The size, shape and location of heating and temperature sensor elements as well as the ceramic substrate geometry were changed to meet the 3D printing requirements.

The typical conventional printhead is made with discrete components, such as the metal mounting block, heating cartridge and thermistor as shown on Figure 2.

Real-time temperature monitoring and controlling

The thermal response of a typical conventional printhead is much slower compared with the new printhead, because it is made with discrete components, such as the metal mounting block, heating cartridge and thermistor as shown on in the broken-line box on Figure 2. The heat generated by the heater has to go through the mounting block and heat up the metal nozzle which the filament goes through and finally reaches the thermistor. The thermistor reading is not really the real-time temperature of the filament being heated due to the multiple layers of thermal "barrier".

On the other hand, the new printhead is a real-time temperature sensing as the sensor element and the heater are integrated on the same ceramic substrate. With the temperature information, the energy level is controlled. An example of control circuit is shown on Figure 6.

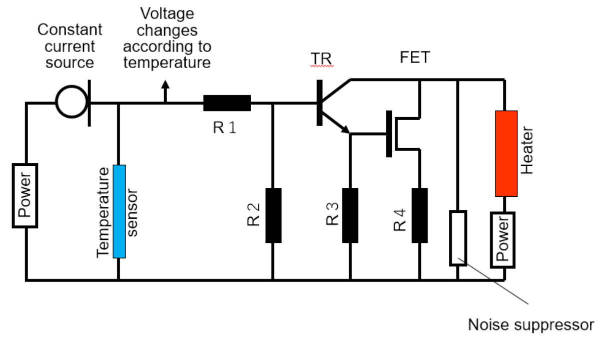

Figure 6
Example of temperature sensing and controlling circuit

Fast temperature rise time (seconds rather than minutes)

The typical existing printheads are made such that they are large in thermal mass and it takes several minutes to go from the cold starting point to operating temperature. The new printhead is made of a pair of ceramic substrates with the heating and temperature sense elements which are sandwiching the filament material. The rise time is magnitude faster as shown on Figure 7. The temperature control is preset at 300˚C, for example, with the circuit above. Rise time is about 10 seconds which is magnitude faster.

The significance of this is not just the rise time – the larger the thermal mass like the typical printhead structure, the slower to react the temperature fluctuations.

The date for the Figure 7 graph is taken with the heat element with 8.5Ω with 14V (23W) at room temperature (12.0Ω 16.3W at 300˚C). The temperature is maintained with modulating the power to the heating element.

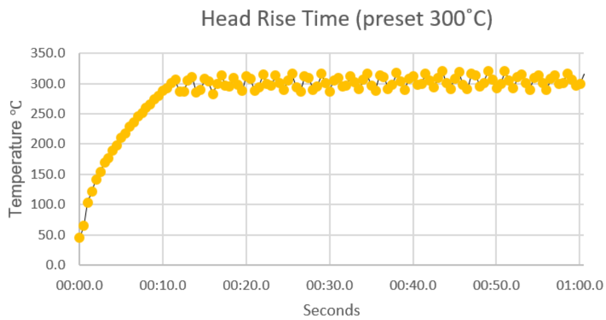

Figure 7
Temperature rise time of new printhead using the controller preset at 300˚C

Extremely energy efficient performance

The typical 3D printhead is configured with a massive heatsink often accompanied by the cooling fan as shown on Figure 1. When the printhead is in operation, it is continuously kept at high temperature. It is wasteful and counterproductive way to operate the printhead as it heats and cools at the same time. The new printhead can heat where and when it is needed which is much better and energy efficient.

Heat-as-needed eliminates/reduces cooling device

As of aforementioned new printhead construction reason, the filament material can be heated as required rather than the whole mounting block heated in order to heat the filament. So, the new printhead's "on-demand-like" and "heat-as-needed" characteristics eliminates and/or reduces the need for the typically large and cumbersome cooling system which is consisted with large heatsink and cooling fun.

Smaller in size and lighter in weight

The new printhead assembly (single nozzle) is shown on Figure 8. The printhead is attached on the mounting block which functions as the holder of power/sensor wires and connecting base for the head moving mechanism.

The size and weight are very important for the FDM 3D printing technology as the printhead has to be moved during the manufacturing process. The smaller and lighter printhead definitely reduces the stress and energy on servo mechanism.

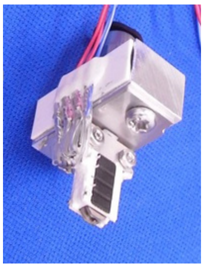

Figure 8
New printhead assembly

Possible to make multiple-nozzle and line-type printhead

This is the most unique feature of the new printhead – a multi-nozzle and line-type printhead can be fabricated. This is impossible to do with the existing printhead technology today.

Since the head part is so small and slim, it is possible to bundle individual printheads to make a multiple-nozzle/line printhead. One of the experimental line-type 3D printheads is shown on Figure 9.

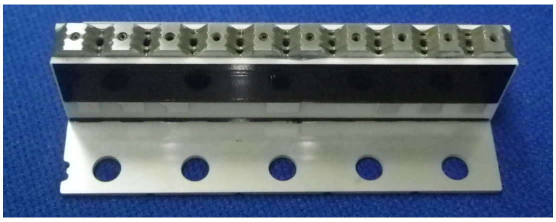

Figure 9
Example of multi-nozzle/line printhead

One of the issues of making the line head is the limitation of dot pitch due to the requirement of physical separation of filaments and the feeding tubes. There are several ways to address this issue. One of the possibilities is to use the mounting block so that the filaments/tubes staggered so that they are not running into each other. From production cost point of view, it will be a challenge to manufacture at reasonable cost. We are in the process of experimenting different methods which will be left for the future discussions.

Applications of the New Printhead

The new printhead, either single nozzle or multi-nozzle, will not be a drop-in replacement for any of the existing printhead due to the physical and electrical specifications differences.

Since we are researching & developing the printhead only, the practical applications will be left up to the hardware and printer manufacturers. However, we can foresee the new applications with the new printhead. With the high-temperature capability of 350˚C, new filament materials and usages undoubtedly will be developed[2].

Potential new applications for the multi-nozzle printheads will be huge as the new printhead can do the current existing heads cannot. Some examples are shown as follows:

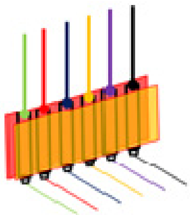

Figure 10
Multi-nozzle line head with various filaments used simultaneously

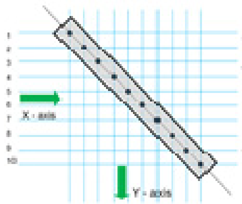

Figure 11
Example of dot pitch can be increase by mounting direction

Figure 10 illustrates the way the new multi-nozzle line printhead can be used for various filaments, such as different component material and different colors or support material. Having multiple nozzles, the material depositing time will be drastically reduced.

Figure 11 is an example of way dot pitch density of the printhead can be increased. In this case, if the dot pitch is 5.0 mm, then it can be reduced to 3.5 mm by mounting the printhead in 45˚ angle.

Evaluation of the New Printhead

The new printhead (multi-nozzle line head) was evaluated in the actual printer (internally built universal test bed) shown on Figure 12.

The test printer is designed to be able to handle the new printhead. This test was run with four different color filaments which were driven with the Bowden method. The sample product is shown on Figure 13.

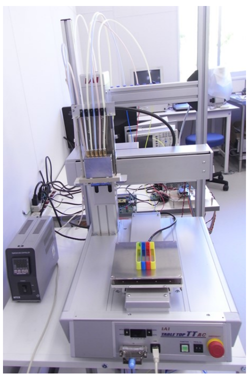

Figure 12
Evaluation of new printhead with 4 filaments

Figure 13
Sample product using 4 filaments with multiple nozzle line-type printhead

Future Outlook

The new single nozzle 3D printhead offers the numerus benefits over the existing printheads as discussed previously. We are confident that the new printhead will broaden the horizon of the 3D printing industry with the higher temperature capability and eco-friendly performance.

The future outlook is even brighter for the multiple nozzle line-type 3D printhead as it can potential cut down the process time significantly. There are, however, some obstacles to overcome – including the cost issue as discussed.

We are confident that the problems will be solved by continuous *kaizen* and innovation. We believe that the future of the new printhead, either single or multi-nozzle is bright as the demand of 3D printing continues to grow.

Conclusion

The 3D printer market is expanding at very fast pace compared with other section of the printer industry[3]. Yet, the majority of printheads employed in FDM printers operates in a very similar way.

The new 3D printhead concept was researched/tested and a very unique on-demand-like FDM printhead became reality. Our goal of our study and development of a new heating head which is efficient, compact and versatile for FDM 3D printer was met with a success.

Market acceptability is unknown at this point and to be seen, but the technical superiority and uniqueness will be attractive feature for the industry.

The more important factor is the possibility to make the multiple nozzle line-type printhead. This will be truly the industry first product when it becomes reality as the process time will be reduced drastically.

References

[1] U.S. Patent # 7206009

[2] Nikkei BP Certification of 3D Printing Skills (in Japanese) 2016, ISBN

[3] Nikkei BP Additive manufacturing and 3D printing guide book (in Japanese) 2015, ISBN 978-4-8222-7637-9

Author Biography

Before founding HIT Research Corporation (HRC) and HIT Devices Ltd., in Kyoto, Hideo Taniguchi worked for ROHM Co., Ltd. for over 40 years where he was responsible for the products including items relevant to the printing industry like thermal printheads (printhead with partial glaze layer, development / implementation of driver ICs on substrate for printhead) and development / mass-production of LED printheads. He received his BS from Ritsumeikan University in Kyoto (in the field of Applied Chemistry) with additional study in Electrical Engineering.

Nobuhisa Ishida has been with HRC from its inception in 2015 and working mainly with the 3D printhead development. Prior to HRC, he worked for ROHM Co. Ltd., in Kyoto and Konica Minolta, Inc in Osaka/Tokyo. Through his career, he had been in the developmental in such field as thermal printhead, inkjet printhead, MEMS micro pump, fuel cell and printed electronics. He graduated from Kansai University in Osaka, Department of Applied Chemistry with BS degree.

Jiro Oi works for HRC since 2015. Prior to joining HRC, he worked for HIT Devices Ltd US Office, ROHM Co. Ltd., US Office and Hitachi, Ltd., in Japan and US. He received his BSEE from California Polytechnic State University in San Luis Obispo, California and MBA from Thunderbird School of Global Management in Glendale, Arizona.