Development of Miniature Flat target X-ray tube for Semi-conductor TSV Non-destructive test imaging

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1. Introduction

The first prototype of miniature X-ray tube was developed for medical purpose. This time our team is developing it for new application method, which is nondestructive miniature X-ray tube for inspection of "Through Silicon Via". To briefly explain TSV, it is a packaging concept of 3-dimensional stacked Semi-conductor. There are micro-scaled vias on the wafers, filled with conductive materials so that electrical connections can be made through all wafer chips.

Due to TSV's small scale, blurring effect caused by focal size is very important. Previous application of miniature X-ray tube used cup-shaped anode target. To reduce focal spot size, and ease blurring effect, author developed flat-shaped anode target for TSV inspection. In this study, author optimized processes of developing miniature X-ray tube with flat-shaped target, then verified its suitability and utility value.

2. Methods and Results

In this section optimization of experimental process and analysis of result will be discussed. Experimental process starts with Focal spot size measurement followed by Sputtering, Conditioning, Brazing, and finally X-ray generation test.

2.1 Measurement of Focal spot size

Theoretically in case of cup-shaped anode target, due to its folded surface the shape of electric field line is distorted making focal spot size larger **Fig.1(a)**. On the other hand, flat-shaped anode target results in smaller focal spot size with constant electric field line **Fig.1(b)**.

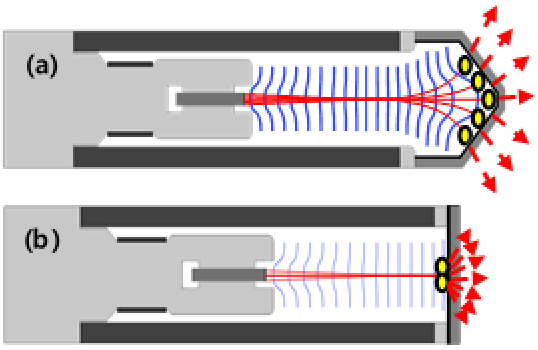


Fig. 1. (a) X-ray tube with cup-type anode target
(b) X-ray tube with flat-type anode target

To verify its theory, author prepared anode target as shown in **Fig.2(a).** To measure the focal spot size, polyimide coating had been carried out. Polyimide changes its color to yellow transiently when it's exposed to thermal condition. As you can find in **Fig.2(b)**, inside the vacuum chamber, author irradiated electron beam using focusing electrode toward coated polyimide film on anode target. By using polyimide's property, author compared the irradiated area between coated cup-type anode target and coated flat-shaped anode target. As you can see in digital image **Fig.3**, cup-shaped target's crushed area, which corresponds with focal spot, is almost twice larger than that of flat-shaped target. Therefore, it is rational to mention that flat-shaped target has better characteristic in imaging field, easing blurring effect.

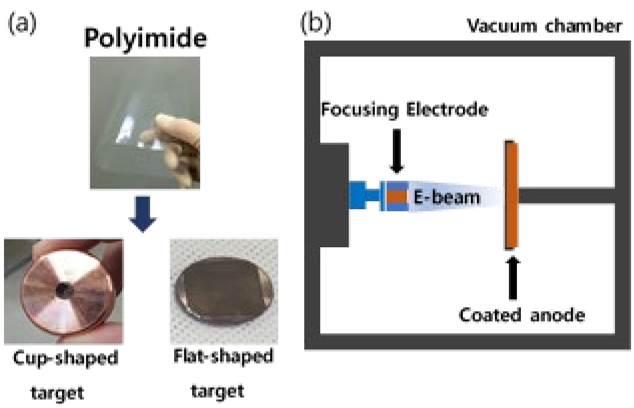


Fig. 2. (a) Cup-type & Flat-type anode target polyimide coating preparation (b) Focal spot size measurement test schematic

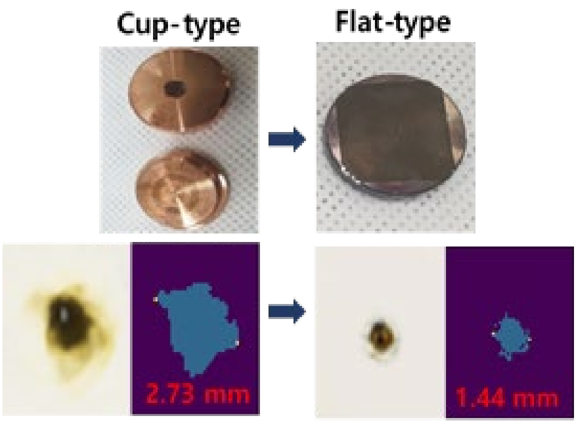


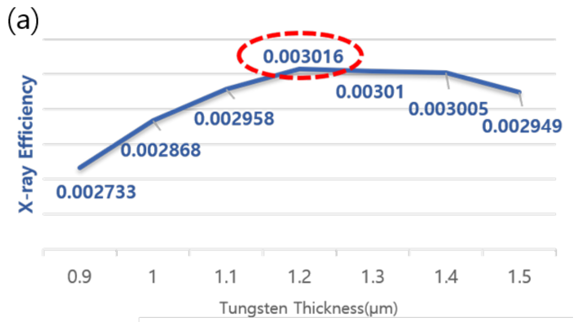
Fig. 3. Focal spot size comparison between cup & flat target

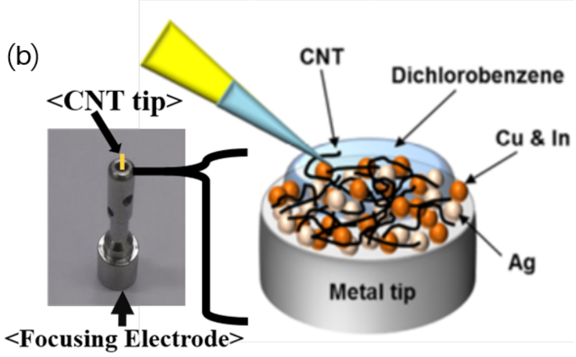
2.2 Sputtering & Conditioning

After confirming that flat-shaped anode target has better property in imaging area, author had to optimize all the other conditions with new shape of target. First author had to set the best thickness of Tungsten sputtered on the target. Tungsten was applied to generate Bremsstrahlung X-ray and author measured its efficiency with Geant4 code. As you can see in **Fig.4(a)**, sputtering 1.2 ㎛ of Tungsten showed best efficiency, which means highest number of gamma ray detected per electron. Referring to the Magnetron Sputtering Metal Coating Device instruction manual device running time was selected to 26min. 40sec..

To generate electron, CNT tip has been used. For stabilization of rough CNT, our team used electric field to smooth the rough parts **Fig.4(b)**. Existence of protruded pieces can be critical when running the X-ray generation test. It's because protruded strand of CNT receives all the voltages arbitrarily, accordingly by smoothing it CNT tip can emit electrons more stably.

Continuing this conditioning process, critical defect has been arose. In spite of continuous electric discharge, those discharges did not made current lower. So as to solve the problem, author took EDX image of focusing electrode. As you can see in **Fig.4(c)**, pieces of CNT have been fluttered away while smoothing process, and stained on the focusing electrode. As a result of those stained CNT pieces, continuous discharge has been occurred. To solve this author used air gun to dust out the CNTs whenever discharge happened, and finally got stable CNT tip.





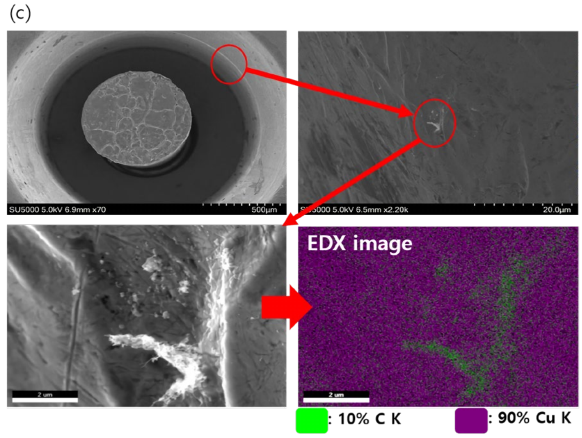
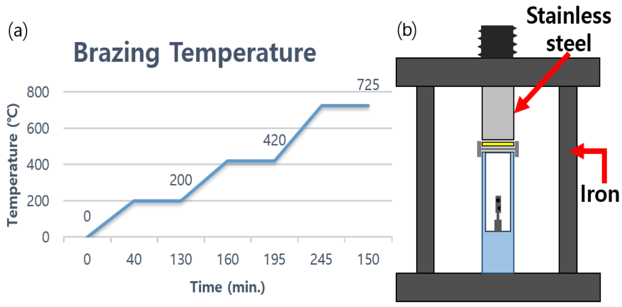


Fig. 4. (a) X-ray efficiency & tungsten thickness relation, unit: # of gamma rays detected per electron
(b) Conditioning process schematic
(c) EDX image of stained CNT on focusing electrode

2.3 Brazing

Anode target and Focusing Electrode with stabilized CNT tips are all prepared in optimized condition. Next step is to combine all the parts, including ceramic tube as container, into one single X-ray tube. In order to irradiate X-ray, it has to be made perfectly vacuum inside the ceramic tube. Wherefore, author used two ways to achieve it. Firstly, approaching highest temperature stage by stage. As you can find in **Fig.5(a)**, brazing temperature did not reached highest temperature immediately. Rather than stay in relatively low temperature. It's a process to bake out the air inside the tube successively. Secondly, As you can see in **Fig.5(b)**, author used different material in fixing pillar and pressurizing cover. For the pillar Iron has been used, and for the cover Stainless steel has been used. The reason to applicate different material is that their thermal expansion coefficient differs, stainless steel is higher than iron **Table I**. Therefore when the temperature goes up, stainless steel as a pressing role will expand much more than iron does, eventually resulting in sealing the tube perfectly. In doing so, miniature X-ray tube has been generated.



	Stainless Steel	Iron
Thermal expansion coefficient (10^{-6}/°C)	17.3	12.0

Fig. 5. (a) Increasing brazing temperature stage by stage (b) Brief schematic of brazing mold using different material at the pillar and the pressurizing cover

Table I. Thermal coefficient difference between Stainless steel and Iron

2.4 X-ray generation test

Last step of generating X-ray tube is to test its stability. Author had to test its discharge condition, therefore X-ray tube immersed in insulating oil. Through this test, author has proved that this flat-shaped target miniature X-ray tube can endure up to 50kV, which means it's stable to use as a imaging device

3. Conclusions

Miniature X-ray tube has its diverse development possibility, and lots of fields to applicate. Among those our team has tried to applicate in medical field, and this time trying to applicate in non-destructive imaging field. Unlike medical field, TSV micro scaled imaging area needed smaller focal size. Thus our team developed new type of anode target, which is flat-shaped target. First author measured its focal spot size to prove it's better than the previous one. Then through various optimization steps written above, author had completed to manufacture flat-shaped target, and finally our development output **Fig.6**. After stability test, author measured its real focal spot size. The result was sufficiently small for TSV inspection. (Longest: 446 ㎛, Shortest: 248㎛) **Fig.7**. In conclusion, miniature X-ray tube with flat-shaped anode target presents satisfactory quality to nondestructively inspect Semi-conductor TSV.

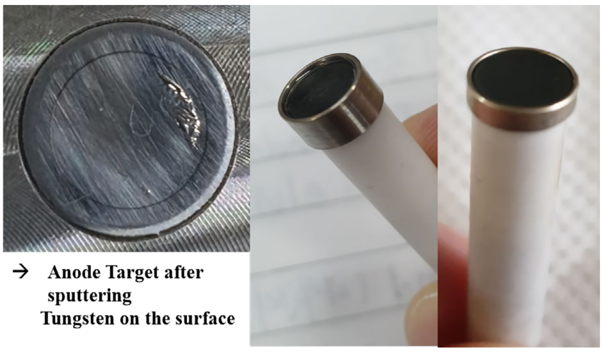


Fig. 6. Left - developed Flat-shaped anode target (Tungsten sputtered) Right – developed flat target miniature X-ray tube

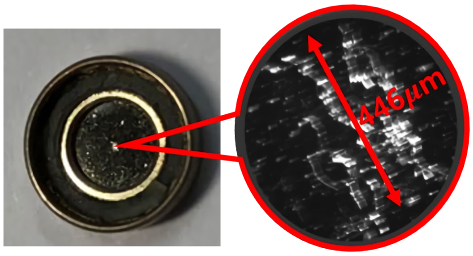


Fig. 7. Real focal spot size from irradiation of developed flat target X-ray tube (Longest: 446 ㎛, Shortest: 248㎛)

REFERENCES

[1] Hyun Nam Kim, Development of a Nondestructive Miniature X-ray System for the Inspection of Through Silicon Via in 3-dimensional Stacked Semi-Conductor Packaging (2017)