Experimental investigations on high-precision microcutting of copper foils with microfabricated silicon punches

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Abstract

The miniaturisation of metallic parts is considerable in various industrial sectors. This trend leads to a demand for decreasing tool dimensions. This study shows the application of monocrystalline silicon as tool material for etched punches used for microcutting of thin copper foils, as etching is a common method in microsystems technology for the economical fabrication of thin vertical structures with a high surface quality. Cutting experiments in a specially designed test rig show the applicability of silicon for microcutting of copper foils and the effect of tool wear on the punching force. The workpiece quality is characterised by a large burnish area of the sheared edges.

1 Introduction

A trend towards miniaturisation of metallic parts made by mass production techniques is still strongly recognisable especially in industrial sectors like the electronics industry. Additionally, increasing requirements on the workpiece quality demand high-precision manufacturing technologies. An appropriate way for producing these parts economically is microforming [1]. One typical manufacturing step for micro parts is cutting, as it offers economic and ecological advantages in comparison to machining and chemical processes. However, the conventional process knowledge cannot directly be transferred to mechanical production in the micrometre range, because occurring size effects change the process behaviour [1]. One specific challenge is the downsizing of the tools and their geometrical details, especially if the tool precision shall be retained. Besides the use of established methods for micro tool production new tool concepts are necessary to overcome these difficulties. The application of techniques and materials known in the field of microsystems technology, like etching of silicon structures, is a promising approach for that.

2 Experimental setup for microcutting with silicon punches

The silicon punches, which are used for microcutting of thin copper foils in this study, were fabricated by wet chemical etching with potassium hydroxide of 4 inch diameter {110} monocrystalline silicon wafers with a thickness of 500 µm. This common process in microsystems technology for achieving thin vertical structures with high aspect ratios was optimised towards high surface quality to prevent fracture originating from micro cracks in the silicon surface [2]. The punch structure had a height of 250 µm, length of 5 mm and a width of 78 µm. For additional wear protection a silicon nitride layer was deposited on the silicon wafer by low pressure chemical vapour deposition after etching. The individual punches with a fixed base area of 5 mm x 5 mm were separated by laser beam cutting and glued onto a steel adapter for better handling. Such a punch system is shown in Fig. 1a. As low bending strength and brittle material behaviour are main challenges for using silicon as tool material, a special test rig was used for the cutting experiments (Fig. 1b). This test rig allows the precise alignment of silicon punch and metal die facilitating the variation of process parameters like punch to die clearances down to 1 µm [2]. A piezo actuator is employed for the generation of the punching force in the compact self-contained test rig.

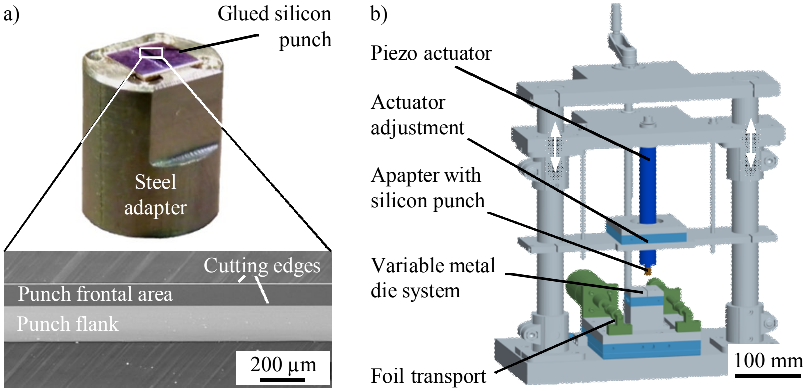

Figure 1: Silicon punch system (a) and test rig for microcutting of thin metal foils (b)

3 Experimental results

For investigations on the process behaviour the silicon punches were used for cutting of copper foils with a thickness of 10 µm, 20 µm and 40 µm. The punches were optically inspected after a number of strokes and the punching force was measured by a force sensor. Fig. 2 shows exemplarily the results for cutting a bar of 3 mm length

Punch material: monocrystalline silicon	Workpiece material: SE-Cu 58
Punch coating: silicon nitride	Foil thickness: t = 10 µm
Punch width: w = 78 µm	Cutting line length: l = 6 mm

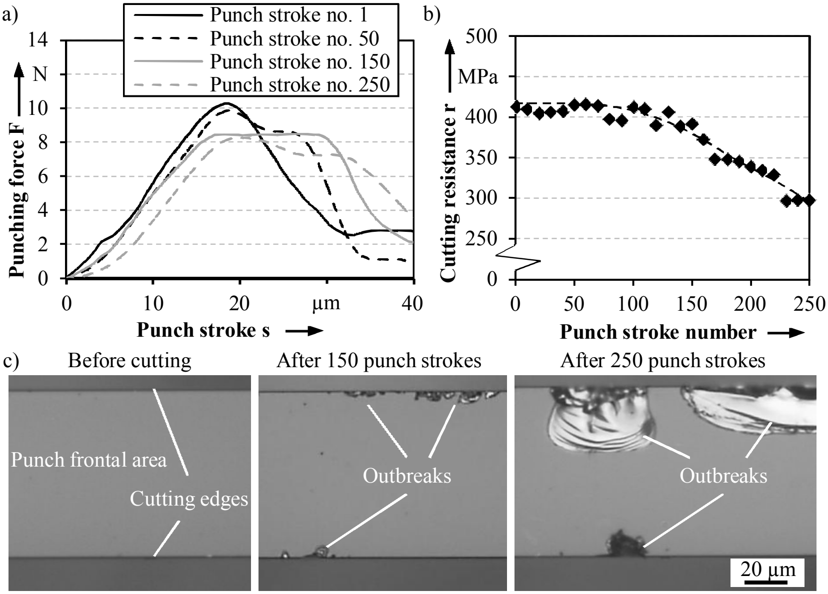

Figure 2: Punching force (a) cutting resistance (b) and light microscopy images (c) of the silicon punch for different numbers of punch strokes

into a copper foil with thickness t = 10 µm with punch to die clearance of 0.1 t. The progress of the punching force punch stroke curve in Fig. 2a shows the typical characteristics for cutting operations. With an increasing number of punch strokes a decrease of punching force as well as a broadening of the curve is recognisable. Also the cutting resistance r, which is the maximum punching force divided by the cutting length and foil thickness, decreases with increasing number of punch strokes (Fig. 2b). Besides this general tendency an abrupt decrease of r can be recognised after approximately 160 and 220 punch strokes. The reason for this behaviour is a gradual wear in form of outbreaks in the cutting edge shown in Fig. 2c. These areas lead to bigger local clearances resulting in a broadening of the shear zone and reduction of punch force. Using the same configuration for t = 20 µm and t = 40 µm a punch break after an average number of strokes of 60 and 3, respectively, shows a dependency of the tool lifetime and the foil thickness. Due to the rising tool load during cutting a foil thickness of 40 µm leads to punch fracture.

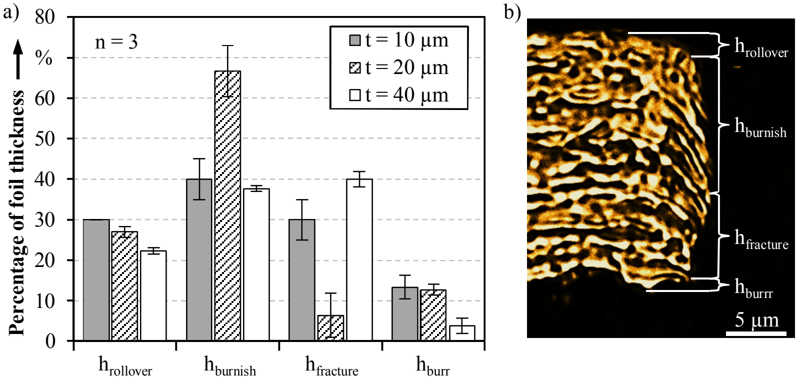

Figure 3: Sheared edge quality of cut foils (a) and a cut copper foil with $t = 20$ µm (b)

For the quantitative evaluation of the workpiece quality the sheared edges were metallographically analysed. The results in Fig. 3 show a high percentage of burnish area for all foil thicknesses in comparison to the other zones. The good results for $t = 20$ µm can be explained by lower punch load compared to $t = 40$ µm and less critical positioning accuracy compared to $t = 10$ µm (punch to die clearance 0.1 t).

4 Conclusions

This study showed the applicability of monocrystalline silicon for cutting thin copper foils with a thickness of less than 40 µm. Due to lower tool load more punch strokes could be performed for lower foil thicknesses. A dependency between punching forces and tool wear in form of outbreaks could be observed. Generally a good workpiece quality was recognisable by metallographic investigations on the sheared edge.

Acknowledgements

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