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Picosecond laser processing for fast cross sectioning and preparation of TEM lamella prior to ion milling polishing

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Abstract

Microchips are more and more complex and designed in thick 3-dimensional packages. Direct observation of the inside of the device by electron microscopy in order to check the manufacturing quality or to analyse the origin of failures requires the removal of huge quantity of matter. The current techniques, such as plasma Focused Ion beam, provide high surface quality but at the cost of a low matter removal rate (~10^4 µm^3/s), requiring hours of processing. This problem becomes worse for the realisation of TEM lamella for which double cavities must be engraved. Therefore, other techniques such as laser engraving are envisioned in order to accelerate the process (Halbwax et al. 2007, Kwakman et al. 2013, Sikora et al. 2016). In this work, picosecond laser micromachining at 343, 515 and 1030 nm was investigated for the realization of cross sections and lamella. By working at a modest repetition rate (200 kHz), much higher matter removal rates could be achieved (~10^6 µm^3/s) reducing the cavity engraving time to several seconds (Sikora et al. 2016). Besides, smooth and almost vertical sidewalls were obtained by tuning the applied fluence and the number of shots. The method is demonstrated for cross sectioning of highly heterogeneous devices such as microchips and for the realization of thin lamella in silicon.

Keywords: engraving; picosecond laser; cross section; TEM lamella; silicon;

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1. Introduction

Failure analysis by electronic microscopy (Scanning Electron Microscopy and Transmission Electron Microscopy) of integrated circuits requires a direct access to the responsible defect. The architecture of these 3D devices (3D System-in-Package) is designed in increasingly complex and thicker structures containing various materials. Accessing deeper buried defects requires the engraving of larger cavities, increasingly tremendously the amount of matter to be removed. The current micromachining tools available such as plasma Focused Ion Beam (FIB) are too slow for this range of volume (Kwakman et al. 2013). Thus, other methods, such as laser engraving prior to FIB polishing (Halbwax et al. 2007, Kwakman et al. 2013, Sikora et al. 2016) are investigated in order to accelerate the process. The FIB polishing duration depends strongly on the achieved surface state of the sidewall. In order to minimize this time, we must achieved sidewalls as smooth and vertical as possible. It has been shown with a 50 ps laser that almost vertical and smooth sidewalls can be obtained by tuning the fluence and the number of pulses (Sikora et al. 2016).

In this work, picosecond laser cross sectioning was investigated in integrated circuits and FIB polishing was tested on the obtained cavities. Moreover, we present an approach allowing to obtain vertical sidewalls in silicon. Using this method, we demonstrate the realization of a thin lamella using only laser micromachining.

2. Experiment

Cross sectioning tests were performed using a fiber laser (Hegoa, Eolite) at three wavelengths (343, 515 and 1030 nm) delivering 50 ps laser pulse duration. The fluence was adjusted with an attenuator based on a half-wave plate (λ/2) and a polarizing beam splitter (PBS). Lamellas were elaborated in phosphorous doped silicon wafers (Si-Mat) using a fiber laser (Hylase, Fianium) delivering 8 ps laser pulses duration at 532 nm.

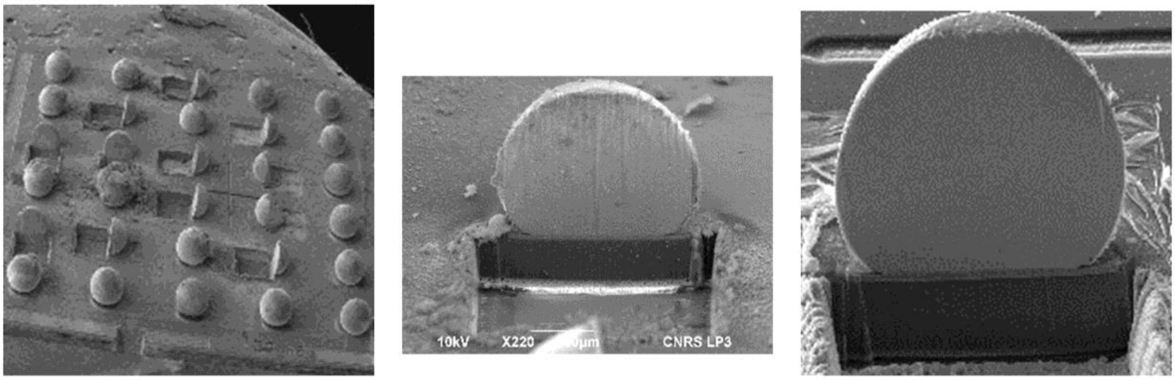
The laser beam was focused on the samples using an Intelliscan 14 scanner (Scanlab) equipped with a 160 mm F(Θ) lens (Qioptiq). The scanner vertical position (Z) and the XY stage were computer controlled allowing a precise positioning of the beam waist at the surface of the sample.

SEM images were acquired with a JSM-6390 microscope (JEOL).

3. Results and discussions

3.1. Cross sectioning of microchips

Laser cross sectioning was tested on different types of microchips. Figure 1a shows an example of laser cross sectioning performed on a Chip Scale Package (CSP) in which a clear interface between the metallic bump and underlayers has to be prepared for microscopy analysis. Cavity engraving was performed for different number of shots and overlaps. Best results were obtained with an applied fluence of 1 J/cm^2, an overlap of ~80% and a scanning direction parallel to the cross section (Fig. 1b). This laser engraving time was ~5 s and would have required more than 1h of processing by plasma Xe FIB at 2 µA. In order to illustrate the typical surface quality that can be obtained after ion milling, the sample was polished by plasma FIB in about 10 mn (Fig. 1 c).



a) b) c)

Fig. 1. a) Global view of the microchip on which the cross sections were performed. b) SEM image of a 350x300x315 μm^3 cross section performed at 343 nm and after 640 scans. c) Same cross section after FIB polishing.

3.2. Elaboration of TEM lamellas

The elaboration of a TEM lamella requires the engraving of cavities containing a vertical sidewall. The sidewall angle of a cavity can be tuned by varying the laser fluence and the number of shots (Sikora et al. 2016). However, achieving full verticality using only these two parameters remains difficult. Thus, another parameter, the laser incidence angle, was investigated. The influence of the beam incidence angle and the laser power are shown in Fig. 2a. By tuning the fluence, the number of shots and the incidence angle, full verticality and even negative slopes can be achieved. An example of a deep cavity containing a vertical sidewall is shown in Fig. 2b) and Fig. 2c). In order to realize the lamella, the previous process is repeated. By controlling precisely the sample position and the engraving parameters, a very thin and large silicon lamella can be obtained (Fig. 2d).

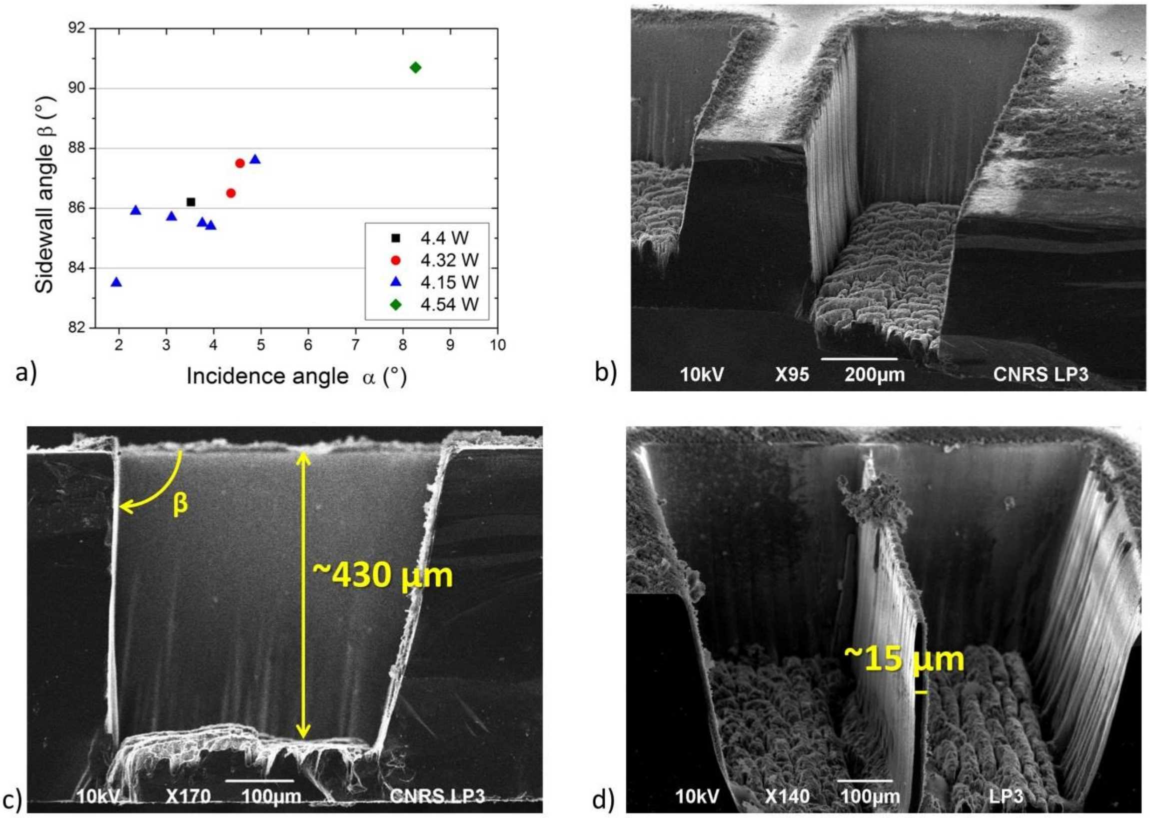


Fig. 2. a) Evolution of the sidewall angle *β* as a function of the incidence angle α for different laser powers. b) and c) SEM images of a 2x0.40x0.43 mm^3 cavity cross section engraved in 48 s at 100 kHz, 4.54 W and after 150 scans. d) SEM image of the laser processed lamella. The cross section was realized on a 2 mm long and ~400 µm deep double cavity.

4. Conclusion

Picosecond laser micromachining allows performing clean cross sectioning of integrated circuits in a few seconds. This method allows to drastically reduce the sample preparation time prior to electronic microscopy analysis.

Vertical sidewalls can be micromachined by tuning the fluence, the number of shots and the incidence angle. By engraving two close cavities, ~15 µm thick lamella can be obtained.

In order to further reduce the FIB polishing time, better sidewall surface quality has to be achieved. The lamella preparation method remains to be tested in microchips.

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