Structural changes in silicon wafer processed by femtosecond laser

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Detection and analysis of defects in Integrated Circuits (IC) is one of the major challenge faced by the semiconductor industry. The use of ion milling IC, although very precise, is time consuming so alternative methods have been considered. To this purpose the use of femtosecond laser as a tool for direct material removal has been intensively investigated and laser engraving of silicon-based structures can be useful for cross-sectioning devices and other applications like direct-write lithography and photomask repair. Femtosecond laser micromachining is usually thought to cause minimal heat-affected zone (HAZ) because the pulse is so short that there is no time for any of the pulse energy to be distributed in the form of heat. This is attributed to the absence of direct coupling of the laser energy into the thermal modes of the material during irradiation. However, it is well known that thermal effects appear in metals when processing is performed in the high fluence regime and phase changes are not observed for low fluence region. In semiconductors the effects can be different, but may occur leading to formation of defects in the vicinity of cut region. In this work, we present on results of micromachining a silicon single silicon surface using 450-femtosecond laser. Micro-Raman spectroscopy showed increasing broadening and downshifts of the 521.6 cm^{-1} Raman peak of crystalline Si with fluence, in the range from 1 to 6 $J.cm^{-2}$. A topographic study showed that the damaged region extends up to distances at about 5 μm far from de scratch edge, and accumulative effect was also observed even for the lower density of energy. The simultaneous frequency downshift and broadening of the Raman peak is a strong indicative of structural disorder originated in the fs laser machining and may be due to laser-induced shock wave. The peak broadening is related to amorphization generated in a superficial layer. Damage threshold experimentally obtained of 0.6 $J.cm^{-2}$ indicates the necessity of machining in conditions very close to this density of energy.
Rate of removed material for different fluencies were obtained from spatial profile of the crater formed by laser shots using an atomic force microscope. In the same experiment lateral force microscopy was employed to determine friction coefficient in the affected surface.

Keywords: femtosecond laser, laser machining, Raman spectroscopy, micromachining
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