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Thin film encapsulation technology for harms using sacrificial CF-polymer

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Abstract

This paper reports on a new method for thin film encapsulation of microelectromechanical systems (MEMS) using plasma enhanced chemical vapor deposited (PECVD) fluorocarbon polymer as sacrificial material and a stress optimized SiO/SiN/Al capping layer. Because of the oxygen plasma-based removal of the sacrificial organic layer, this technique is applicable for a wide range of MEMS technologies—from surface to high aspect ratio microstructures. It saves die area compared with bonding techniques and enables standard packaging processes such as dicing, pick and place and plastic injection molding. Beside of the fabrication technology, we present results of the finite element analysis (FEA) regarding the deflection and the mechanical stress in the cap. The results of the FEA have been verified on fabricated structures by interferometric measurements.

Keywords: Wafer-level packaging; Thin film encapsulation; HARMS; CF-polymer

1. Introduction

Most MEMS require hermetic encapsulation for protection against the atmosphere, moisture, particles and mechanical as well as electro-magnetic loads, which could damage fragile parts or influence their performance. Furthermore, for specific applications as damped oscillators or pressure sensors, a dedicated pressure has to be enclosed in the cavity of the package. The protection of the released MEMS prior to dicing can be obtained by wafer-level packaging (WLP). Two main approaches for WLP are currently in use. The first method is wafer bonding. A cap wafer, e.g. silicon, glass or ceramic, is bonded on the MEMS wafer, creating a cavity around the microstructures. For surface microstructures several low temperature bonding methods, e.g. glass frit [1], eutectic [2], solder [3] and adhesive [4] bonding, have been developed. These techniques are commercialized and well established but costly, because they require a second substrate, double the thickness of the chip, and need additional die area for the sealing frame.

The second approach is based on surface micromachining processes for creating thin film membranes as capping layer. These thin film encapsulation (TFE) technologies are based on a sacrificial layer which is covering the microstructures during deposition of the encapsulating film. For surface microstructures mostly inorganic materials like SiO_2 are used as sacrificial material [5,6]. However, sacrificial etching of silicon dioxide could be a serious challenge in combination with micromachining technologies containing Al or SiO_2 as structural material. Organic materials, which can be easily removed in oxygen plasma, are an interesting alternative. Liquid coatable polymers like photoresists [7] or thermally decomposable poly-carbonates [8] have been suggested, but coating of the materials on fragile structures and the thermal stability of the polymers are crucial for process integration.

This paper presents a TFE technique which is applicable to a wide variety of near surface and high aspect ratio microstructures (HARMS). It is based on fluorocarbon polymer (CF-polymer) as organic sacrificial layer. The polymer is deposited by PECVD, covering the microstructures without filling the trenches. This enables the planarization of microstructures, independently of their aspect ratio. The CF-polymer is temperature stable up to 400 °C [9] allowing subsequent PECVD for deposition of the capping layers. The dry processing of the sacrificial polymer by

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PECVD and oxygen plasma removal prevents even very sensitive structures from sticking without sophisticated techniques. The capping membrane is formed by PECVD of silicon oxide. But also other materials like amorphous silicon are possible. Hermeticity is attained using PECVD silicon nitride (SiN_x:H_y) and sputtered aluminum for encapsulation. The material stack was optimized regarding minimal thermal and intrinsic stress in the thin film cap.

2. Fabrication technology

For demonstrating the encapsulation technology, it was applied on HARMS, fabricated by the air gap insulated microstructures (AIM) technology [10]. The process flow of the TFE technique is shown in Fig. 1. After patterning the silicon microstructures by deep reactive ion etching and releasing the movable elements, the sacrificial CF-polymer was deposited, closing the trenches and defining the cavity of the thin film package. The PECVD of the polymer has been done in a P 5000 DxZ CVD chamber (*Applied Materials*) at 250 W RF- and 120 W LF-power, 270 °C, 4 mbar and a deposition rate of 220 nm/min. For adhesion improvement a 10 nm CH layer was deposited beneath and on top of the polymer [9]. Fig. 2 shows SEM images of the polymer covering the microstructures. The growth rate in lateral

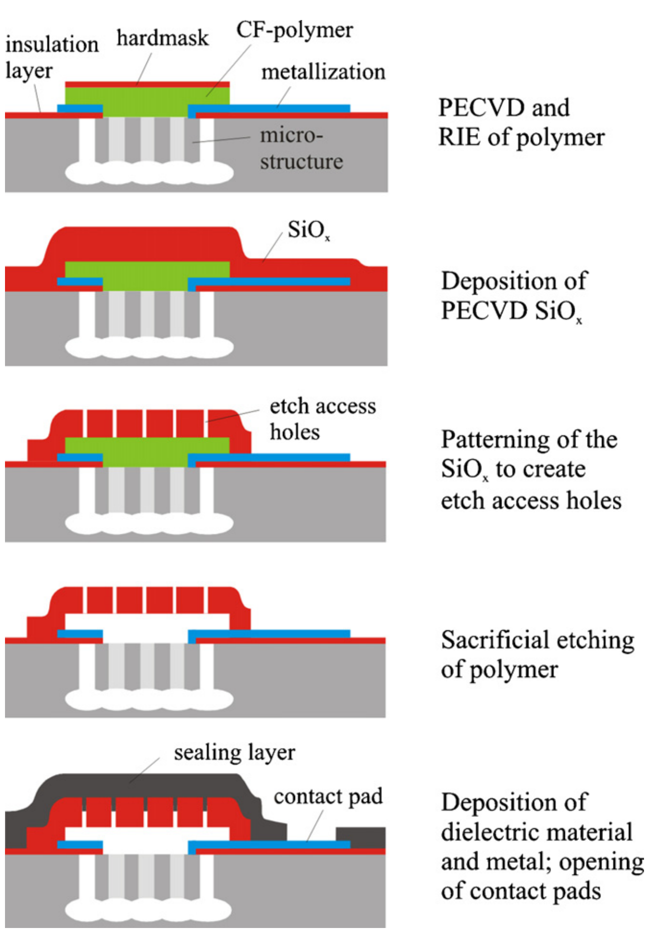

Fig. 1. Schematic process flow of the CF-polymer-based TFE technology applied to an air gap insulated microstructure.

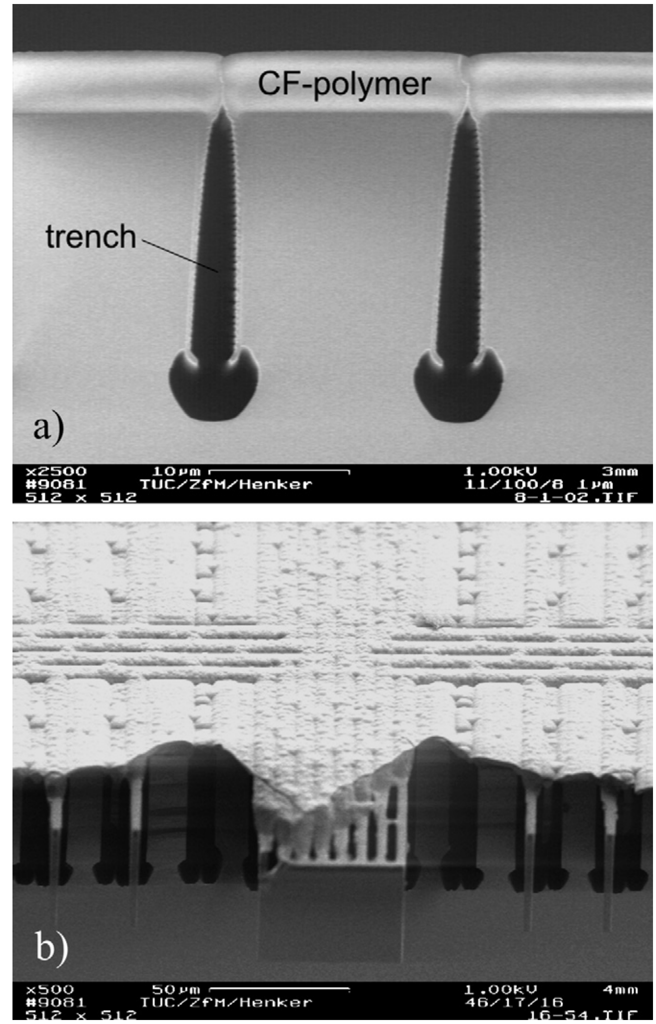

Fig. 2. SEM images of (a) cross-section of the CF-polymer layer covering a single trench and (b) top view of covered AIM structure.

direction is approximately one half of the vertical deposition rate.

For defining the lateral dimensions of the thin film cap, the polymer has to be patterned by anisotropic etching. Therefore we used reactive ion etching (RIE) with oxygen as process gas in an inductively coupled plasma (ICP) chamber. Because of the thickness of the polymer layer, a high etch rate, high selectivity to the SiO masking layer and good uniformity is needed. These demands can be met by using high ICP power, medium bias power and low process pressure.

After patterning the polymer the first silicon oxide (SiO_x) layer of the membrane is deposited by PECVD (Fig. 3a). A low deposition rate process is used, providing a 1.5 μm thick film with low residual stress (0 to −20 MPa) and good step coverage. Etch access holes for removal of the sacrificial layer are defined in the oxide via RIE (Fig 3b).

The CF-polymer is etched in a barrel reactor using oxygen plasma, 800 W microwave power and 2 mbar process pressure. The process has a highly isotropic characteristic (Fig. 3b) which is important for effective release of the membrane layer. In order to increase the distance between the etch access holes, a high