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Sputtered Pt electrode structures with smoothly tapered edges by bi-layer resist lift-off

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ABSTRACT

A lift-off process using a bi-layer resist consisting of an image reversal resist on top and a lift-off resist at the bottom was used to structure Ti–Pt thin films. DC magnetron sputtered metal films patterned by this process show ultra smooth edges, ideal for applications such as interdigitated electrodes in resistive gas sensors including thin-film based sensitive coatings with thicknesses below 100 nm. Profiles of processed structures were analyzed by scanning electron microscopy and surface profilometer. The thickness profile and structure width were controlled by using different resist thicknesses and undercut lengths. Results were compared with iterative simulations by a geometric shadowing model, predicting undersputtering length and profile structure of the experimentally manufactured samples in good agreement. Target-to-substrate distance variation was found to have only a minor influence on the sputtering result.

1. Introduction

Platinum is often used when a thin film metal should withstand high temperatures and harsh chemical environments. Its unique properties such as chemical inertness and high temperature coefficient of resistance [1] make it the material of choice for miniaturized resistive gas sensors which require temperature stable heaters and contacts [2,3]. Other applications include soot particle sensors [4] as well as piezoelectric actuators and sensors [5].

Thin film interdigitated electrodes (IDEs) are widely used for contacting resistive thin or thick films [3,6] in miniaturized metal oxide gas sensor applications. They are usually deposited under the sensitive coating to maximize the surface and to avoid contamination of the chemically sensitive layer by further processing such as wet chemical etchants or solvents. Four major problems are encountered when structuring the metal layer: Short contacts across an insulating surface due to residues from fences, contact problems due to void or crack formation close to a step [7], metal particles that redeposit on the substrate surface, and incomplete lift-off (retention). The first two issues result from steep edges of metal structures [3], which can occur both in plasma etching and in lift-off structuring of metal films. Fabrication of underlying electrodes in metal oxide gas sensor applications [8] as well as microlenses [9] and optical waveguides [10] demand structures with a smooth edge profile. Thus it is important to find a reliable process which can generally be used in this kind of applications. We present a method which shows a good possibility to control both the width of the structures and the steepness of the metal layer edges. In this work ultra-smoothly tapered edges were obtained by application of a lift-off technique for platinum with a bi-layer resist. Both the resist thickness and the undercut length were varied.

The use of a single thin resist layer results in very steep edges. Generally lift-off processes can be realized either using a negative resist or a double resist as a sacrificial layer for the deposition (Fig. 1(a)). In the case of a negative resist, the deposition of the metal film on the sidewalls is suppressed by the negative edge profile of the thick resist. This is due to UV-light absorption in the upper part of the resist layer during exposure which increases resist solubility during development at the bottom part of the resist. This effect depends on the resist thickness. An image reversal resist can be used instead of a negative resist [11,12,13]. Here, after a mask exposure step and a reversal bake, the positive edge profile of the resist is inverted by flood exposure. In the case of the bi-layer resist, the negative edge profile is achieved by the use of a non-photo-structurable resist which is structured during the development process and yields in a defined undercut as indicated in Fig. 1(a). As non-photosensitive resists, lift-off resists (LOR) are based on a polymethylglutarimide platform [14] and were selected as candidates. They can be used for producing of both high resolution [14] and high aspect ratio structures [15].

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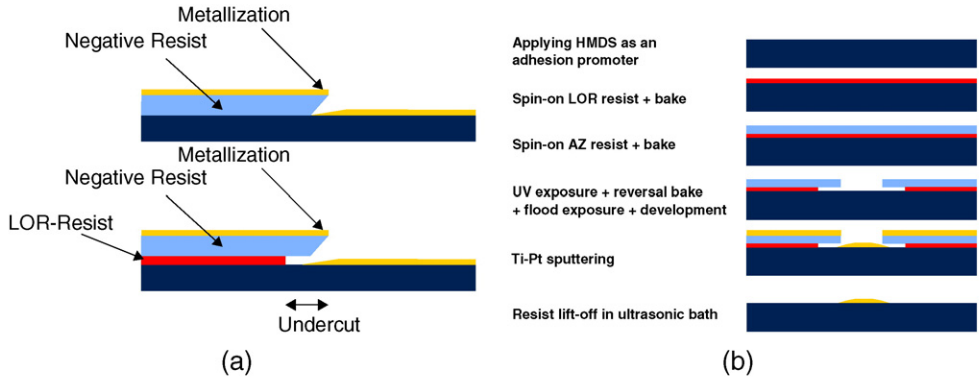

Fig. 1. (a) Schematic drawing of resist structure for use of resist with negative edge profile (upper image) and double resist (lower image). (b) Overview of the lift-off process.

2. Experimental details

A bi-layer-resist [16] was used to optimize the platinum contacts, as shown in the process overview (Fig. 1(b)). Silicon 150 mm wafers (p-type) were hexamethyldisilazane coated in an oven to improve resist adhesion followed by spin-on of LOR resists (MicroChem Corp.) in various thicknesses (300 nm, 500 nm, 900 nm and 1500 nm (Süss MicroTec AG spin coater RC8) and by baking at 190 °C for 3 min on a hotplate (Desaga Thermoplate, Sarstedt AG & Co.)). AZ5214E image reversal resist (AZ Electronic Materials Corp.) was subsequently applied by spin-coating with a thickness of 1.3 μm and the substrates were prebaked at 110 °C for 1 min on an automatic hotplate (Hamatech, Singulus Technologies AG). The image reversal resist was processed as a negative resist. The resist was UV exposed using contact lithography (Süss MA 150). The intensity of the mask aligner was 15 mW/cm^2 and the development time was 40 s. A first exposure series was applied to the image reversal resist to optimize the lithography result. Five different first exposure doses were used ($7.5-37.5$ mJ/cm^2) and a dose of 22.5 mJ/cm^2 was found optimal for an accurate geometric transfer of the mask structure to the resist. Reversal bake took place for 2 min at 120 °C followed by a flood exposure of 300 mJ/cm^2 which was kept constant for all samples. The substrates were developed under manual agitation at room temperature using AZ726 MIF developer (tetramethylammmonium hydroxide 2.38%, AZ Electronic Materials Corp.) until the windows in the resist were optically clear. An over-development phase followed, the time was varied to achieve different undercut lengths of the LOR resist.

Structured platinum films were fabricated using the lift-off process with titanium as an adhesion layer. Ti–Pt-films were DC magnetron sputtered on the structured resist using a Leybold Z590 sputtering tool and targets with 200 mm diameter in an argon atmosphere (pressure 0.94 Pa). The substrate carrier was rotated with a speed of 3.5 rpm. No correction aperture was used. Typical film thicknesses were 30 nm (Ti) and 160 nm (Pt) with a resulting film thickness inhomogeneity over the substrate of about 12%, determined by stylus profilometer (Tencor P-10) measurements over steps. The substrate carriers were water cooled to avoid resist degeneration during the deposition process. For both metal depositions, the sputtering power was kept at 900 W. The process time and pauses were varied as well as the target-to-substrate distance, which was set to either 60 mm or 90 mm. The latter lowered the deposition rate by about 10%. The lower rate was compensated by a longer sputtering time.

Lift-off was performed by first soaking the sputtered wafers in dimethyl sulfoxide at 40 °C for one hour followed by an ultrasonic bath at the same temperature for an interval between five minutes and one hour. The time was dependent on the lift-off result. The geometric structures in the resist were analyzed using an optical microscope before sputtering. Stylus profilometer measurements were performed at steps of the resist to determine the thickness. As-sputtered samples as well as samples with lifted resist were analyzed in scanning electron microscopy (SEM) (Leo Gemini 1530 at 3 kV operation voltage and Hitachi Tabletop Microscope at 15 kV operation voltage) along breaking lines. Structured metal films were analyzed by an optical microscope (Olympus, software analySIS), SEM and profilometer measurements.

3. Calculation

Simulations were introduced to clarify the influence of the resist structure and deposition parameters on the resulting resist profile. The deposition process was simulated using a simple geometric model

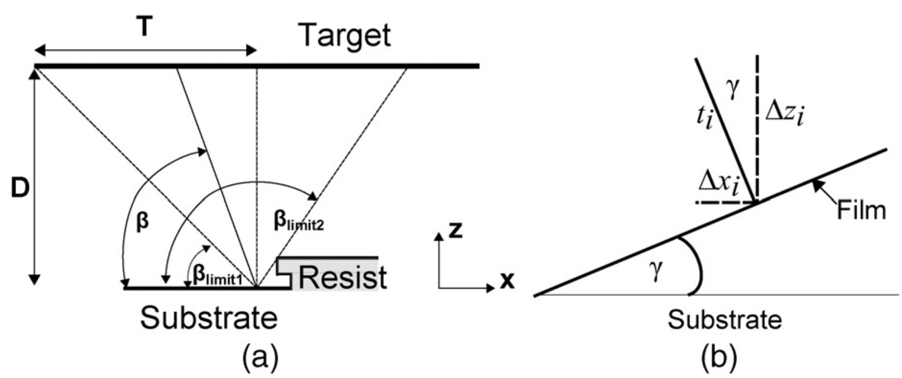

Fig. 2. (a) Schematic drawing of the substrate and target geometry. The integration limits β_{limit1} and β_{limit2} and the sputter angle β are marked; (b) schematic drawing showing the inclination of the surface, see text.