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Chemical etching of Tungsten thin films for high-temperature surface acoustic wave-based sensor devices

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ABSTRACT

Surface acoustic wave devices are widely used as wireless sensors in different application fields. Recent developments aimed to utilize those devices as temperature sensors even in the high temperature range ($T > 300$ °C) and in harsh environmental conditions. Therefore, conventional materials, which are used for the substrate and for the interdigital transducer finger electrodes such as multilayers or alloys based on Al or Cu have to be exchanged by materials, which fulfill some important criteria regarding temperature related effects. Electron beam evaporation as a standard fabrication method is not well applicable for depositing high temperature stable electrode materials because of their very high melting points. Magnetron sputtering is an alternative deposition process but is also not applicable for lift-off structuring without any further improvement of the structuring process. Due to a relatively high Ar gas pressure of about 10^{-1} Pa, the sidewalls of the photoresist line structures are also covered by the metallization, which subsequently prevents a successful lift-off process.

In this study, we investigate the chemical etching of thin tungsten films as an intermediate step between magnetron sputtering deposition of thin tungsten finger electrodes and the lift-off process to remove sidewall covering for a successful patterning process of interdigital transducers.

1. Introduction

During the last two decades, the development of surface acoustic wave devices had seen a boost due to a major progress in radio frequency (rf) filters, wireless communication techniques and microfluidic research. However, the use of surface acoustic wave (SAW) devices at temperatures above 300 °C or under harsh environments require particular materials with a high thermal stability, reliability and lifetime for the piezoelectric substrate as well as for interdigital transducer (IDT). Current SAW-based high temperature sensors favourize langasite (LGS) as substrate material in combination with Platinum based electrode materials [1–4]. Investigations on the temperature stability of these Platinum based electrodes showed diffusion of Gallium from the substrate into the electrode [5] which can lead to phase formation. Tungsten seems to be an alternative compared to Platinum and in combination with diffusion or covering layers an appropriate metal for high temperature applications not only because of a higher melting point but also a reduced activation energy for self-diffusion and lower electrical resistivity [6,7]. Due to its high melting point, the deposition of tungsten by electron beam evaporation is very hard to control which seems to be a big disadvantage. Hence, magnetron sputtering is more suitable than electron beam evaporation although the process also involves difficulties especially regarding patterning of the tungsten films.

The higher gas pressure during sputtering ($\approx 10^{-1}$ Pa compared to 10^{-3} Pa for E-beam) implies an increased collision probability of particles that are moving towards the substrate. The resulting wide angular distribution of the particle drift velocity leads to a covering of the sidewalls of the photoresist lines (see Fig. 1). In this case, the removal of the subsequent lift-off process is not successful i.e. the metal lines are not fully structured. As it can be seen from Fig. 1b, the thickness “d” of this sidewall covering is usually smaller than that of the electrode height “h”. An intermediate etch process for instance by wet chemical etching can help to remove this sidewall covering, which should enable the following lift-off structuring step. Therefore, a proper etchant and well-known characteristics of the etching process have been evaluated to etch thin tungsten layers deposited by magnetron sputtering. The big advantage of this method is to combine sputtering technique with the low-cost lift-off-process, which is still a standard method to achieve structured metal lines in SAW technology.

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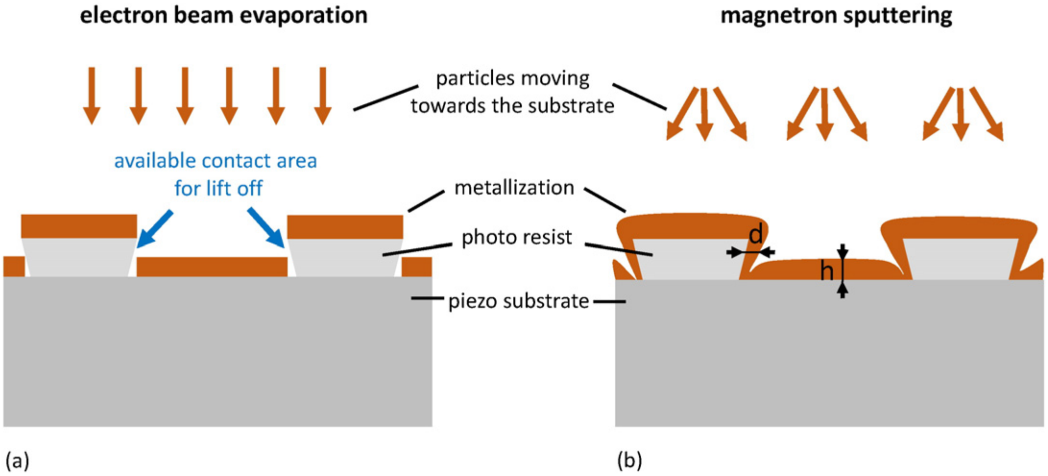

Fig. 1. Schematic demonstration of the effect of the sidewall deposition intensity of the photoresist mask by deposition of metal using a) electron beam evaporation and b) magnetron sputtering. The sidewall covering of the resist line avoids their removal by the solvent during the lift- off process.

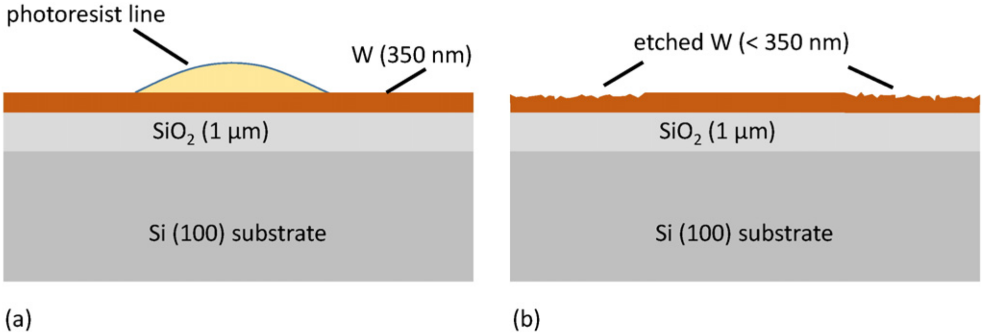

Fig. 2. Schematic cross section view of the etching test samples to study the tungsten etching process. (a) before and (b) after chemical etching.

Table 1
Chemical composition of etching solutions (in deionized water).

Notation	% (w/w) H_2O_2	% (w/w) NH_3
W30	30.0	0.0
W21A0	21.3	0.0
W21A1	21.3	1.0
W21A7	21.3	7.3
W10	10.0	0.0

2. Experimental methods

The following test structure was designed to determine tungsten-etching rates under different conditions: Tungsten films with a thickness of 350 nm have been deposited onto Si (100) wafers with a 1 µm thick SiO_2 film by magnetron sputtering under a process pressure of $1.7 \cdot 10^{-4}$ Pa and an Ar flow rate of 30 sccm. The wafer was notched into square shaped samples each with dimensions of 10 × 10 mm^2.

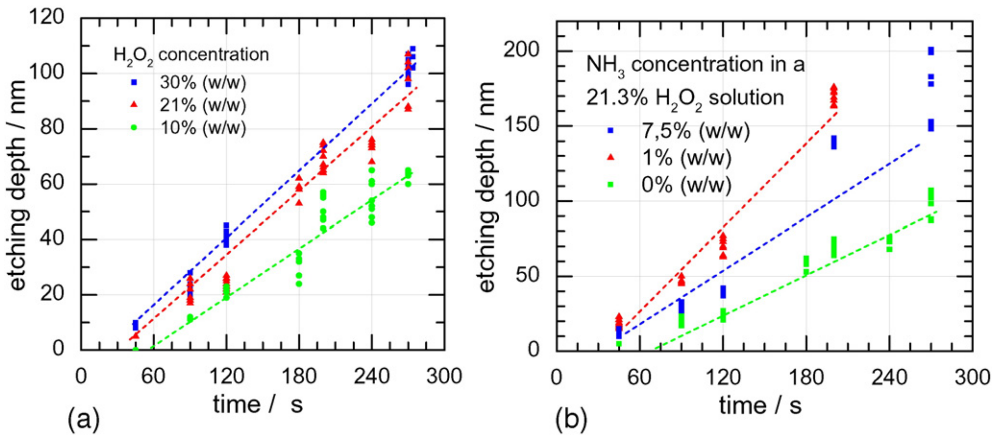

Fig. 3. Etching rates for 350 nm thick tungsten layers on Si substrates using different compositions of the etching solution. (a) H_2O_2–based etchant without ammonia (b) 21.3% (w/w) H_2O_2–based etchant with varying amount of NH_3.