DESIGN AND FBRICATION OF 2D PHONONIC CRYSTALS IN SUYRFACE ACOUSTIC WAVE MICRO DEVICES

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Abstract

There has been a growing interest in studies of periodic dielectric composite structures during the past two decades. Transparent dielectric periodic arrays are capable of inducing stop bands within certain frequency ranges, i.e., photonic crystals. Recently, the application of photonic crystals has become an exciting topic for line defect waveguides [1], sharp bending of light [2], and so on. In the 1990s, it was discovered that there is a considerable analogy between electromagnetic waves and elastic vibrations [3-4]. The repetitive structures made up of different materials can prevent elastic waves from passing by at some specific angles or in certain frequency bands, and are called phononic crystals.

In this paper, we present the design and fabrication of innovative phononic crystals integrated with two sets of interdigital (IDT) electrodes for frequency-band selection of surface acoustic waves (SAW). Fig. 1 shows the schematic diagram of the 2D phononic crystals in SAW microdevices. Silicon substrate is used because it can be easily patterned to form high-aspect-ratio crystals. Zinc oxide is used as the piezoelectric layer for its simple fabrication process of deposition and wet etching. Aluminum is the electrode material because its small density generates a negligible mass loading effect, and therefore the central frequency is not shifted. Analogous to the band-gap generated by photonic crystals, the phononic crystals with two-dimensional repetitive structures composed of two different materials can prohibit the propagation of elastic waves with either specific incident angles or certain bandwidths[5]. As a result, the photonic crystals can be filled with various materials to study their influences on the frequency band gap.

Table 1 lists the design parameters. The spacing between two inter-digits is one-fourth the wavelength of SAW. To confine the prohibited bandwidth to the order of one hundred MHz, the diameter of crystal pores is 6.0μm and the aspect ratio of each pore is 3:1.

Fig. 2 shows the fabrication process flowchart[6]. First, a 1.5-micron zinc oxide layer, which provides well-defined central frequency, is sputtered on the silicon substrate. This piezoelectric layer is then patterned with a H_3PO_4/HAc/DI water (1:1:10) solution. The etch rate is about 50nm/sec. Then the exposed silicon substrate is etched using DRIE to generate two-dimensional phononic crystals. To tune the prohibited SAW bandwidth, the crystal pores are filled with copper by thermal evaporation of the seed layer, followed by electroplating. It should be noted that two different plating electrolytes are used in this study. The basic electrolytes, listed in Table 2[7], include 0.25 mol/L $CuSO_4$ and 1.8 mol/L H_2SO_4, *to which a combination of 1.0×10-3 mol/L NaCl (Cl)*. In the other electrolyte, 8.8×10-5 mol/L $H(OCH_2CH_2)_{55}OH$ (PEG, average molar mass ~ 3400 g/mol) is added. The purpose of the PEG addition is to achieve superfilling in the deep silicon pores. A comparison of the plating results with the PEG additives is shown in Fig. 3. After using copper etchant ($HAc+H_2O_2$+DI water =1:1:20) to remove the superfluous copper above the silicon substrate, the copper residue attached to the photoresist above the silicon substrate is removed with acetone. Finally, the IDT is deposited using e-beam evaporation and patterned by lift-off techniques. The fabricated devices are shown in Fig. 4.

For this paper, we studied the propagation of high frequency SAW in 2-D phononic structures with micrometer scales and constructed the copper/silicon pore array to investigate the phenomenon of the phononic band gap. The energy of surface acoustic waves, measured along the [100] direction, obviously vanishes with great attenuation when the central frequency is in the range of 152.46MHz to 182.20MHz. The measured signals approximately match the simulated responses. Results of this paper can serve as a basis for integrating surface micromachining and bulk-micromachining techniques to fabricate 2-D phononic crystals.

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Table 1 Design parameters of layered SAW device and phononic crystals

Configuration	Parameter		
Electrode	Aluminum		
λ (μm)	28.0	24.8	21.6
IDT pairs	40		
IDT aperture (μm)	100λ		
Delay line (μm)	10λ		
IDT thickness (Å)	2000		
Diameter of crystal pores, $2r$ (μm)	6		
spacing of pores, a (μm)	10		
Depth of pores (μm)	more than twice λ		
Thickness of ZnO (μm)	1.5		

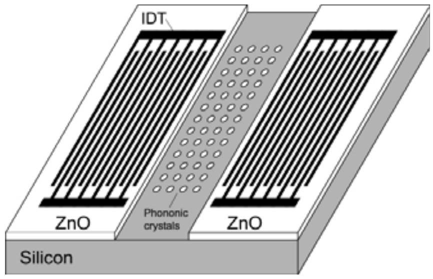

Figure 1. Schematic diagram of 2D phononic crystals in SAW micro devices.

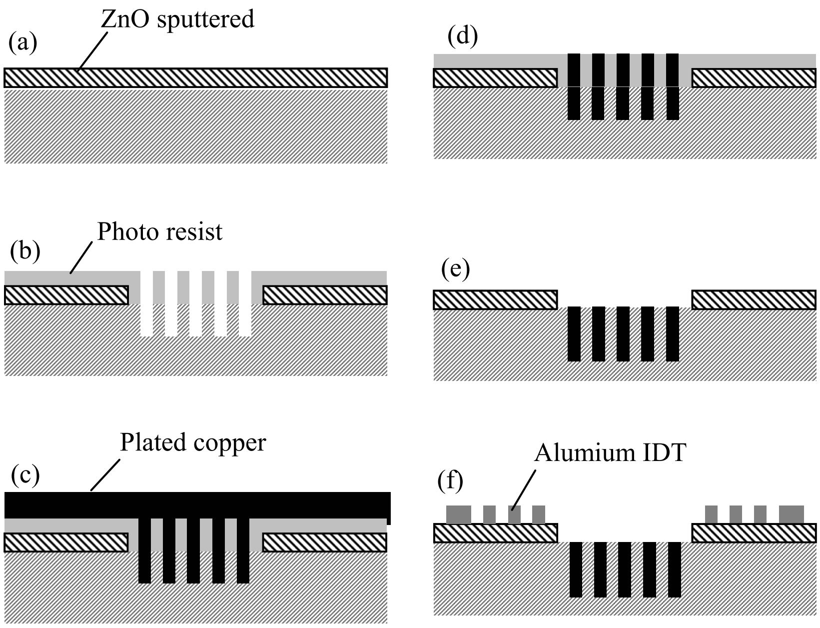

Figure 2. Fabrication process for 2D phononic crystals in SAW micro devices.

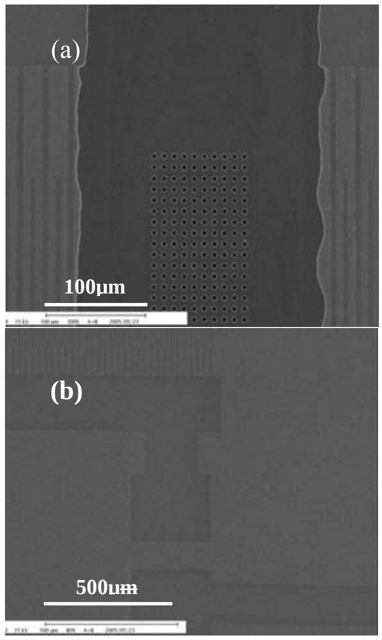

Figure 4. (a) SEM picture of 2D phononic crystals in SAW micro devices. (b) SEM picture of aluminum pad of IDT.

Table 2. Electrolyte composition (mole/L)

	Basic electrolyte
H_2SO_4 • 5H2O	0.25
H_2SO_4	1.8
Cl^-	1×10^{-3}
PEG (3400 Mw)	0
pH	1.2~1.7
Current density (A/m^2)	300

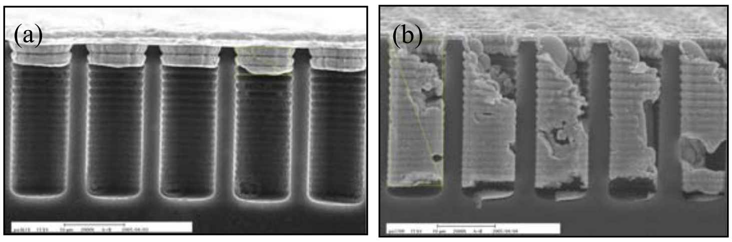

Figure 3. Cross-sectional SEM pictures show the effect of bottom void (a) without and (b) with PEG additives in the plating electrolytes.