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Sensors and Actuators A 141 (2008) 598–602
SENSORS AND ACTUATORS A PHYSICAL
www.elsevier.com/locate/sna

Solidly mounted thin film electro-acoustic resonator utilizing a conductive Bragg reflector

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Received 1 November 2006; received in revised form 20 August 2007; accepted 6 September 2007
Available online 14 September 2007

Abstract

A new design of a solidly mounted resonator (SMR) that utilizes an all-metal Bragg reflector eliminating thus the need for a bottom electrode is proposed. In this configuration, the role of the bottom electrode is taken by the Bragg reflector rendering the resonator “combined electrode-Bragg reflector SMR”. The main advantages of the proposed design are the substantially reduced electrode resistance (and hence higher Q), the utilization of the full piezoelectric coupling at high frequencies as well as expected improvement in power handling capabilities due to lower dissipation and improved heat conductivity. Resonators with the classical and the new design have been fabricated and evaluated. The measurements indicate that indeed the resonators with the new design demonstrate improved performance.
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Keywords: Micromachined acoustic resonator; AlN; Bragg reflector; Equivalent circuit

1. Introduction

The standard single crystal electro-acoustic (EA) technology is a well established technology with billions of components manufactured annually and used in virtually every aspect of today’s IT society. The need for band pass filters operating in the lower gigahertz frequency range, where low cost single crystal solutions becomes costly, resulted in the development of a new EA technology based on the use of thin piezoelectric films. The latter has made substantial progress in recent years. Further, this new technology opens the way for integrating the traditionally incompatible integrated circuit (IC) and EA technologies, bringing about substantial economic and performance benefits. The fabrication equipment available today allows sputtering of highly c-orientated thin aluminum nitride (AlN) films with extremely good thickness and functional uniformity. The research is mainly focused around thickness-excited modes in view of resonator and filter applications. [1–5]. Currently two different device designs are independently and simultaneously being developed. The first based on the membrane topology has been extensively studied in the last 20 years and currently demonstrates a device quality factor (Q) approaching 2000 at around 2 GHz [1]. The drawbacks of the membrane approach are related to the relatively limited power handling capabilities [6] and the reduced sustainability to stresses in the thin films. As an alternative approach, thin film solidity mounted bulk acoustic resonators (SMR) utilizing distributed bulk reflectors have also been developed.

A SMR consists of a piezoelectric thin film sandwiched between two thin electrodes and is fabricated directly onto a carrier substrate, see Fig. 1a. To acoustically isolate the SMR from the substrate, it is fabricated on top of an acoustic mirror, called a Bragg reflector. The Bragg reflector consists of a sequence of a quarter wavelength thick layers of low and high acoustic impedance, respectively [7]. At each layer interface of the Bragg reflector, a part of the acoustic wave energy is reflected. The number of layers in the Bragg reflector needed for complete wave reflection is determined by their acoustic impedance ratio. Typically, high impedance layers are fabricated from tungsten (W), molybdenum (Mo), tantalum oxide (Ta_2O_5) or aluminum nitride (AlN), and the low impedance layer from silicon dioxide (SiO_2) [8,9].

Currently, the limitations of the SMR technology are associated with the relatively lower quality factors achieved. Recent improvements in reflector optimization [10] and minimization

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0924-4247/$ – see front matter © 2007 Elsevier B.V. All rights reserved.
doi:10.1016/j.sna.2007.09.002

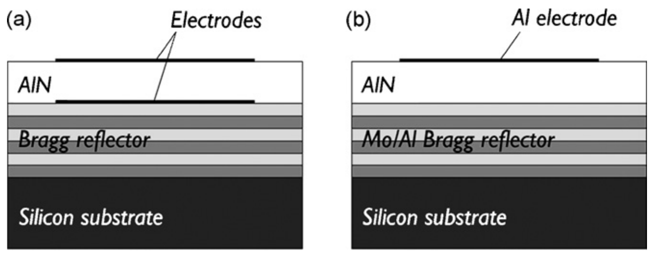

Fig. 1. Resonator cross-sections: (a) conventional SMR with two thin electrodes; (b) design with an all metal Bragg reflector.

of the degrading contribution of the laterally propagating modes [11] have been proposed. Thus, significant improvements in the quality factor at parallel resonance have been demonstrated. The somewhat smaller improvement of the device Q at series resonance is attributed to the degrading influence of the parasitic series resistance. This is expected to be even more pronounced at higher frequencies of operation as the electrodes become thinner.

In this work, the emphasis of device optimization is on the minimization of the parasitic resistance. The combined electrode-Bragg reflector design proposed inhere can be combined with the optimization techniques discussed above and thus a trade off between acoustic and resistive losses can be achieved. Other potential advances of the approach used in this work are also discussed.

Two one-port SMRs, having a conventional and "electrodeless" design, respectively, are fabricated. The device schematics of the proposed designs is shown in Fig. 1. For both types of devices the Bragg reflector consists of a set of aluminum/molybdenum (Al/Mo) pairs, each layer having a thickness of one quarter wavelength. The conceptual difference between both designs is in the topology of the first layer in the underlying stack. In the conventional design this is a 200 nm Al electrode deposited on top of a quarter wavelength SiO_2 layer, while for the combined electrode-Bragg reflector design it is simply one quarter wavelength thick aluminum which in fact is part of the reflector stack. Thus, the combined electrode-Bragg reflector SMR is fabricated such that the bottom electrode is incorporated into the Bragg reflector. It is to be noted that the used techniques for thin films synthesis are specific. Thus, only devices fabricated at equal conditions are compared in here. In order to compare the designs proposed, the devices are electrically characterized and physical parameters extracted through a specially modified Butterworth-Van-Dyke (BVD) equivalent circuit. The results obtained are discussed and the potential benefits outlined.

2. Design and fabrication

The SMRs are fabricated on polished 4-in. silicon wafers with the thickness of the various layers as given by Table 1. Prior to any deposition, the substrate was cleaned using RCA cleaning. For the "combined electrode-Bragg reflector" SMR a six layer Bragg reflector is then formed by alternately depositing quarter wavelength thick films of Mo and Al. Sheet resistivity of 0.014 Ω/sq for the Bragg stack is measured. In the case of the conventional SMR the top layer of the Bragg reflector consists of a quarter wavelength thick SiO_2 as discussed above. In addition, 200 nm Al bottom contact having sheet resistivity of 0.12 Ω/sq is formed. All metal layers have been deposited using a sputtering technique at room temperature. The SiO_2 layer has been deposited using plasma enhanced chemical vapor deposition (PECVD).

Table 1
SMR configuration and design parameters

Layer	Material	"Metal reflector"	Conventional
Top metal	Al	400 nm	200 nm
Piezo	AlN	2.5 μm	2.5 μm
Bottom metal	Al	–	200 nm
Reflector	Al/Mo	550/680 nm	550/680 μm[a]
Area	–	900 μm^2	900 μm^2

[a] A 0.65 μm thick SiO_2 layer replaces the Al top layer in the reflector.

After formation of the reflector stack, a highly textured AlN film has been deposited by means of pulsed DC reactive magnetron sputtering [12–14]. The target was powered by an ENI RPG50 asymmetric bipolar-pulsed DC generator. The applied frequency was 250 kHz. The vacuum chamber was evacuated by a 800 l/s turbo molecular pump to a base pressure of $<5 \times 10^{-8}$ Torr prior to deposition. The process gases were introduced into the process chamber via mass flow controllers. During deposition the ratio of Ar/N2 was 0.5 and total flow was fixed at 60 sccm. The Al target had a diameter of 6 inches and a purity of 99.999%. The target-to-substrate distance was 55 mm. The power applied to the target during deposition was 1200 W. No external heating was applied to the substrate. The thickness of the AlN film on each substrate was 2.5 μm at the center of the wafer. A summary of the process parameters are given in Table 2.

After deposition, the AlN film was passivated with a silicon dioxide layer (SiO_2). The passivation layer is used to protect the AlN surface from damage and contamination introduced by any subsequent process steps. In order to contact the bottom electrode, the AlN film was patterned with a thick resist, AZ4652 and via holes etched in a Ar/Cl2/BCl3 inductively coupled plasma. Subsequently a 2 μm aluminum contact pad was sputter deposited and patterned by means of low-resolution lithography. The active (top electrode) area of both resonators was defined by etching appropriate holes in the passivating SiO_2 with a buffered hydrofluoric acid (BHF). Finally, 200 nm (0.12 Ω/sq) and 400 nm (0.055 Ω/sq) thick Al top electrodes have been

Table 2
Deposition parameters for c-axis oriented AlN

Target	Al (99 999%)
Substrate-to target distance	55 mm
Base pressure	$<6.65 \times 10^{-6}$ Pa
Process pressure	0.266 Pa
DC power	1200 W
Ar gas flow rate	20 sccm
N_2 gas flow rate	40 sccm
Deposition rate	∼1 nm/s

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