MICROWAVE LOW INSERTION LOSS SAW FILTER BY USING ZnO/SAPPHIRE SUBSTRATE WITH Ni DOPANT

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ABSTRACT

Microwave low insertion loss SAW filters are realized by using ZnO epitaxial film on sapphire substrate. The epitaxial growth conditions and dopant are carefully determined to realize low propagation loss and high stability. 1 5 to 2.5GHz range SAW filters are fabricated with the insertion loss of only 1 to 2dB and the outline dimensions of 0 01 to 0.02cc.

INTRODUCTION

To miniaturize mobile communication equipments, Surface Acoustic Wave (SAW) filter becomes very important device for RF and IF stages, because of its small outline dimensions and also high electrical performance In recent years microwave SAW filter has been realized by fine line lithography technology developed for semiconductor devices, still the electrical performance, especially the insertion loss, was inferior to that of dielectric filter. To reduce the insertion loss, we paid attention to the intrinsic propagation loss of SAW mode and made choice of Sezawa wave of ZnO thin film on sapphire substrate. This substrate is well known theoretically but there was almost no practical application because of poor reproducibility of ZnO epitaxial film. We adopted RF planar magnetron sputtering process to realize ZnO epitaxial film of high quality [1] By using this process and Interdigitated Interdigital Transducer (IIDT) resonator filter design, we succeeded to realize very low insertion loss SAW filters in microwave band [2]

This paper reports the other key technology of the dopant to compensate n-type semiconductivity of ZnO and the performance of newly developed SAW filters for various applications in microwave band

SUBSTRATE MATERIAL - ZnO/SAPPHIRE

There are many kinds of SAW substrate materials, such as Quartz, $LiNbO_3$, $LiTaO_3$, piezoelectric ceramics and so on. RF bandpass filter of mobile communication equipment should have wide pass bandwidth and low insertion loss characteristics, and then 64°Y-X $LiNbO_3$ and 36°Y-X $LiTaO_3$ single crystal substrates are generally used because of their high electro-mechanical coupling coefficients, ks (Table 1). But the SAWs on these substrates are not conventional SAW (Rayleigh wave) but leaky SAWs, and have intrinsic leakage loss

$(11\bar{2}0)$ZnO/$(01\bar{1}2)$sapphire (R-plane sapphire) substrate can propagate higher order Rayleigh type SAWs and the first higher order of these SAWs is called Sezawa wave. This Sezawa wave is well known because of its high propagation velocity (Vp) and high ks theoretically (Fig.1 and Table 1), but there was almost no practical applications. We paid attention to this Sezawa wave because Rayleigh type SAW has no leakage loss. The propagation loss should be low if ZnO film is highly crystallized epitaxial film However, ZnO epitaxial film generally shows intrinsic n-type semiconductivity The resistivity is very low without some impurity (dopant), and that film has almost no piezoelectricity.

Table 1 SAW substrate characteristics

Substrate	Vp (m/s)	ks^2 (%)	TCD (ppm/K)	Att. const (dB/λ)
36°Y-X LT	4100	6 5	35	0 04
64°Y-X LN	4450	10 9	70	0 08
ZnO/sapp.	5200 ..5500	4...4.7	43	0.012

Note) measured and estimated data
attenuation constant : in metal-strip grating area at 1GHz

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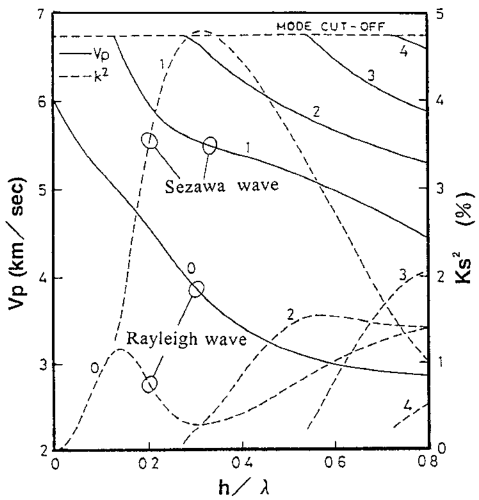

Fig 1 Theoretical Vp, ks dispersion of ZnO/Sapphire substrate

We examined various dopants and found that Ni is very effective Ni doped ZnO epitaxial film has high resistivity of over 100Mohm·cm at Ni content of over 1wt%. We fabricated and estimated ZnO/sapphire substrate with various Ni content Fig.2 and Fig 3 show the relationships between Ni content and X-ray diffraction quality, propagation loss, respectively.

Table 2 Aging characteristics vs Ni content

Ni content	1wt%	2wt%	
frequency shift	151	45	ppm
insertion loss shift	0.21	0.03	dB

frequency : 1GHz +85°C, 100hours

Smaller content of Ni shows better crystalline quality and lower propagation loss and the propagation loss at Ni 1wt% is almost same as that of single crystal ZnO

On the other hand, aging characteristics are also measured and we found that more than 1wt% of Ni content is preferable regarding long term aging characteristics (Table 2) Then Ni content is determined preferably between 1 and 2wt%

Concerning the epitaxial growth process, we adopt RF planar magnetron sputtering process. We are also using this process for the mass-production of polycrystalline ZnO film on glass substrate for TV-IF SAW filter more than 10 years. The feature of this process is to use planetary type substrate holder and this process shows high reproducibility, high uniformity and high productivity.

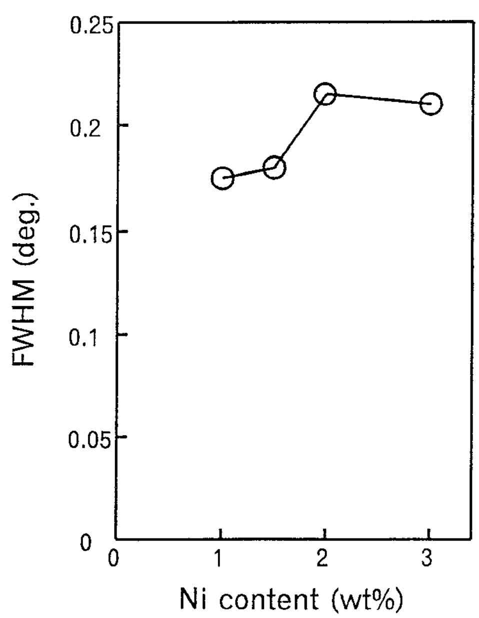

Fig 2 Full width at half maximum of $(11\bar{2}0)$ZnO diffraction vs Ni content in ZnO

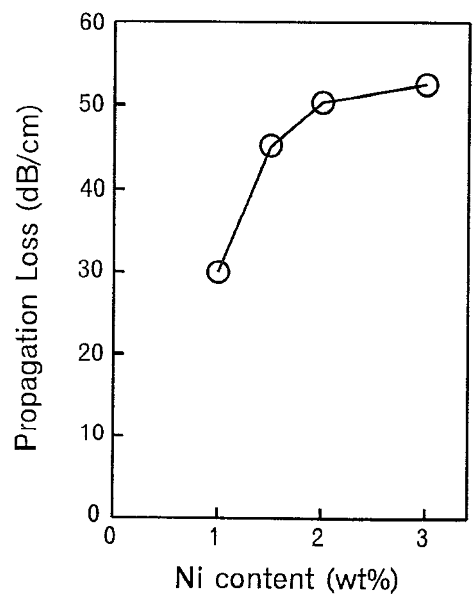

Fig.3 Propagation loss vs Ni content in ZnO

The sputtering conditions are shown in Table 3. The differences from the conditions for polycrystalline film are metal Zn target instead of ZnO ceramics and relatively high substrate temperature.

Table 3. Sputtering conditions.

Target	metal Zn (Ni doped)
substrate holder	planetary motion
sputtering gas	$Ar:O_2$=50.50
gas pressure	0.7 Pa
substrate temperature	250°C
deposition rate	1 μm/hr

DESIGN AND FABRICATION

The electrode design is based on IIDT design [3,4,5], and additionally, longitudinally (in-line) coupled resonator design is applied [2,6] to expand the fractional bandwidth. 5 and more IDTs are used to decrease ohmic loss of the electrodes and also to increase fractional bandwidth The accurate design is performed by our computer simulation program based on Smith's equivalent circuit model modified by Kojima [7] Measured dispersion properties of ZnO/sapphire structure are considered in addition

The substrate structure is Al electrode/ZnO/sapphire and the thickness of Al is 0 025 to 0 03λ (wave length), relatively thick to increase the stop bandwidth [2], and the thickness of ZnO is 0.26 to 0.3λ. Sezawa wave has high velocity of over 5000m/s, still the line and space width of IDT becomes so narrow as 0.88μm at 1.5GHz range and 0.53μm at 2.5GHz range To fabricate such fine electrode patterns on ZnO epitaxial thin film, we apply i-line stepper and lift-off process

After the formation of Al electrodes on ZnO, the wafer is diced and separated. The die is mounted and wire-bonded in alumina leadless chip carrier (LCC) package. The outline dimensions of alumina LCC is 3 8mm square by 1.5mm in height (0.02cc) or 3.0mm square by 1.2mm in height (0.01cc).

EXPERIMENTAL RESULTS

Various SAW filters were designed in microwave band 1 5GHz SAW filter (Fig 4) was reported as only 1dB insertion loss, aiming at Rx antenna filter of PDC1500 (Japan digital cellular) handheld terminal [2]. This SAW filter needs no external impedance matching circuits with 50ohm.

This filter shows insufficient attenuation at upper side of the passband and so this filter is not suitable as Tx filter. Then we developed Tx filter, adopting one-port SAW resonator in series with IIDT resonator filter in one chip. Fig.5 shows measured data of this Tx filter with the attenuation of 20dB at upper side duplex frequency band.

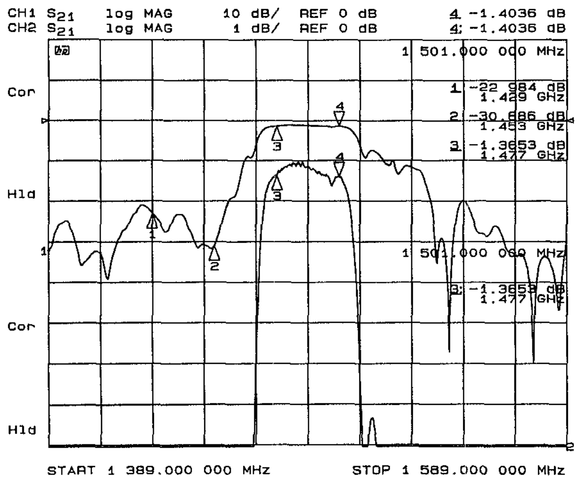

Fig.4 Measured frequency response of 1.5GHz SAW filter for PDC1500 Rx

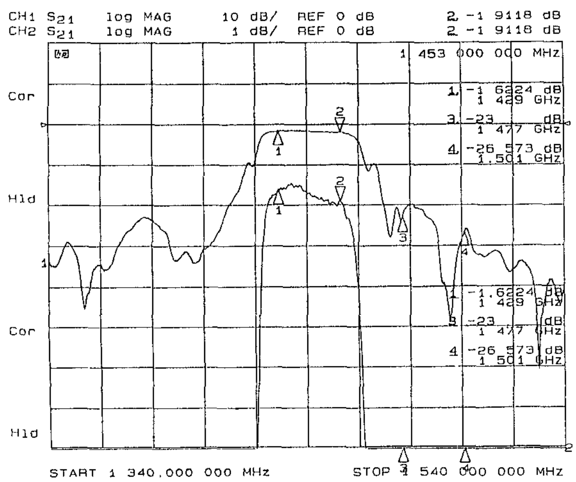

Fig 5 Measured frequency response of 1 5GHz SAW filter for PDC1500 Tx

Fig 6 shows measured data of 1.575GHz SAW filter for GPS receiver. This filter has two SAW resonators, one in series and the other in parallel with IIDT resonator filter This filter shows excellent near-by attenuation characteristics with low insertion loss of 2dB

Fig.7 shows measured data of 2 5GHz SAW filter Minimum insertion loss is 1.8dB and the bandwidth at the insertion loss of 3dB is 44MHz The outline dimensions of this SAW filter are 3.0mm square by 1.2mm in height

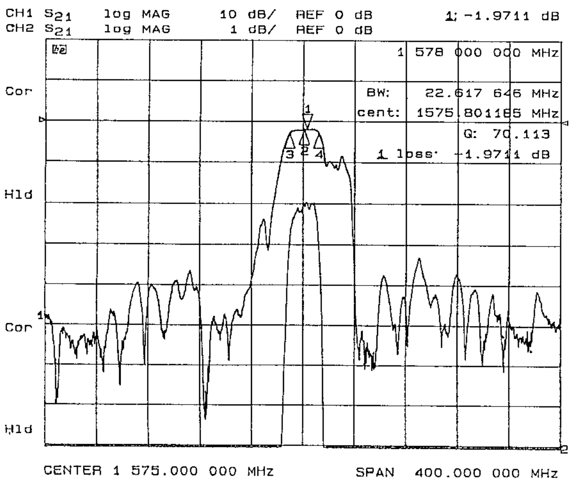

Fig.6 Measured frequency response of 1 575GHz SAW filter for GPS

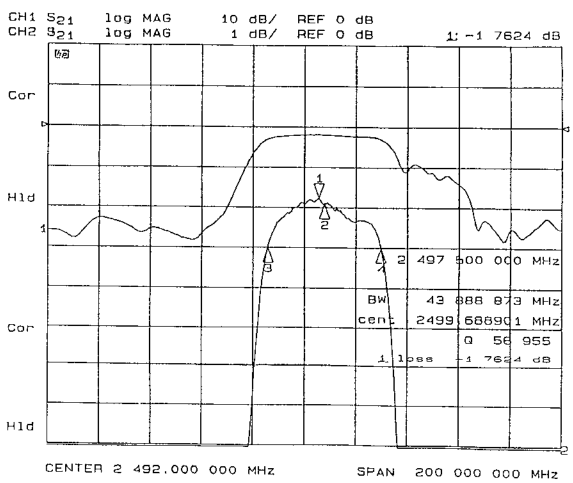

Fig 7 Measured frequency response of 2 5GHz SAW filter

CONCLUSION

Microwave low insertion loss SAW filters are realized by using Sezawa wave of ZnO epitaxial film on R-plane sapphire substrate. Ni dopant realizes ZnO epitaxial film of high resistivity, high quality and high stability, and RF magnetron sputtering process with planetary holder realizes high productivity Low insertion loss of 1 to 2dB range are realized in 1 5 to 2 5GHz range with small outline dimensions of 0.02cc to 0.01cc

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