DRY ETCHING FOR HIGH POWER SAW DEVICES

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Abstract

The addition of Ti, Ge, and Zn to sputtered Al electrodes is investigated, to obtain both high power durability and fine-dimensional control in high-frequency surface acoustic wave (SAW) devices. Ti is more effective than Ge, Zn or conventional Cu. The improvement in the electrode durability at a high SAW power is related to the grain refinement and the static stress incorporated by addition of Ti, Ge, Zn and Cu by sputter deposition. For Ti addition to Al, dry etching (reactive ion etching) with gases containing BCl_3 can be more easily performed than in the case of Cu addition. By using RIE and dyed UV positive-type resist, the line-width deviation of 1.2-microm electrodes can be improved to the small value of 95 nm, which is 40% of that in the conventional wet-etched case.

Introduction

High-frequency surface acoustic wave (SAW) devices, particularly as used in mobile phones, require high-power durability and fine-dimensional control for the Al electrodes. To obtain the fine-dimensional control, dry etching of Al electrodes has been utilized, because of its precise pattern replication with vertical side walls. On the other hand, to obtain the durability, various elements have been added to the electrodes[1]. When propagating large-amplitude SAW using Al electrodes, failures arises that are similar to those induced by electro-migration in silicon devices[2], and which limit the reliability and input power range. Such failures are considered mainly to be the results of mechanical migration: mass transport influenced by high-frequency SAW stress[1]. This can be controled by grain-boundary diffusion. The stress and failures increase with frequency and input power. To prevent such failures, a small mount of Cu has conventionally been added to the thermally evaporated Al electrodes used in SAW devices. These Al+Cu electrodes have other shortcomings in the dry-etching process[3]: corrosion defects are induced by the Cu remaining on the SAW substrates, in combination with H_2O and Cl from chlorinated etching gases[3]. In this paper, Ti , Ge and Zn are investigated as additives that are more compatible with dry etching using chlorinated gases. The characteristics of the films, such as grain size and static stress, are also investigated in relation to the durability. In Al+Ti electrodes, which show the highest durability in this study, dimensional control is investigated by using reactive ion etching (RIE) with BCl_3 -containing gases and a dyed UV positive-type photo-resist.

High-Power Durable SAW Electrodes

Additive Related to Dry Etching

Dry etching works well when the elements of the films react with the etching gas to produce volatile compounds. For the dry etching of Al with chlorinated gases, conventional Cu addition causes difficulties, as known in LSI manufacturing. ($CuCl_3$ is non-volatile [4] due to its high boiling temperature as shown in Table 1.) It should be noted that Li contained in $LiTaO_3$, or $LiNbO_3$ substrates also behaves similarly. Table 1 lists Ti, Ge and Zn as candidates for the additives to Al electrodes, also Cu and Si for comparison. It also shows their chlorides, with boiling temperatures. Among these additives, Si gives little improvementin the durability of SAW resonators[3]. In this paper, the durability at a high SAW power is investigated for the additions of Ti, Ge and Zn .

Table 1. Additive and their chloride

Additive	Chloride	Boiling Temperature (℃)
Si	$SiCl_4$	57.6
Ge	$GeCl_4$	84.0
Ti	$TiCl_4$	136.4
Zn	$ZnCl_4$	732.0
Cu	CuCl	1490

Experimental Procedures

A d.c. magnetron sputtering system (ANELVA, SPF 420-HL) was used to deposit the electrode films and an electron beam (EB) evaporator was used for comparison of the properties of the resulting films. The deposition conditions were already reported [3]. Two-port SAW resonators were prepared as test media for the durability at a high SAW power. Packaged resonators underwent an accelerated aging test at a temperature of 120℃ and an input power of approximately 100mW. Here, the time to failure (TF) was defined as the aging time at which the peak-frequency shift reaches 50kHz. Additional samples were prepared for compositional and structure analysis, and for film-stress measurements. These measurements items, methods, and samples are listed in Table 2.

Table 2. Measurements and samples

Measurements	Samples
Durability:	2-port SAW resonator
Accelerated aging	on ST-cut quartz
	696 MHz, QL=4000
Composition: ICPS, RBS	on Si substrate
Structure : TEM	on rock-salt
Residual stress :	on $LiTaO_3$, -36ºYX
Curvature change	(2 inches Φ, 0.35mmt)

Substrate Temp:200 ℃, Film thickness : 0.1 micron

Durability of Electrodes to SAW Stress

In this section, the data for resonator TF are considered in relation to SAW stress τ, in the films. The results of the accelerated aging tests are summarized in Fig.1, showing the dependence of TF on the square of τ. The results of pure Al electrodes (EB evaporated and sputtered) and Al+Cu electrodes (EB evaporated, and sputtered containing approximately 0.7 and 3.8wt% Cu, respectively) are also shown for comparison. The slopes of the lines in Fig.2 show that TF varies as τ^{-6}. Fig.1 also shows that sputtered pure Al films have 10^3 times higher durability than EB pure Al films, and also have a rather higher durability than EB 0.7wt% Cu films. Furthermore, for Ti addition to sputtered pure Al electrodes, this figure shows that 0.4 and 0.8wt% Ti materials has a nearly 3 and 4 times higher durability, respectively, than for EB 0.7 wt% Cu.

For Cu addition, even increasing the concentration to 3.8wt% in a sputtered film, the durability is about half of that for sputtered 0.8wt% Ti materials. For 2.5wt% Ge addition and 1.7wt% Zn addition, the durability is about the same in each case. While the durability of these electrodes is lower than that for 0.4wt% Ti, it is a little higher than that for 3.8 wt% Cu sputtered material.

These results reveal that sputtering is more effective than EB evaporation, and that Ti is more effective than Ge, Zn or conventional Cu, in increasing the durability at a high SAW power. In transmitter filters for cellular radio duplexers[5], the Al+0.4wt% Ti material shows a longer lifetime in accelerated aging than the 0.8wt% Ti one, in contrast to Fig.1. The reason is that the higher electrical resistivity of the 0.8wt% Ti material induces a higher temperature rise, thermally accelerating the mechanical migration[6].

Electrical Resistivity

Increasing the resistivity of the electrodes not only degrades the insertion loss, but als accelerates the unwanted migration. Fig 2 shows the resistivity of 0.1-micron thick sputtered Al+Ti, Al+Ge and Al+Zn films as a function of additive concentration, compared to that of an Al+Cu film of the same thickness. The slope as a function of Ti addition is notably larger than that for Cu addition. On the other hand, the measured loss of the SAW devices with added Ti is slightly smaller than that for Cu addition, when both electrodes have the same resistivity. The reduction of the resistivity deviation is an issue in these sputtered films.

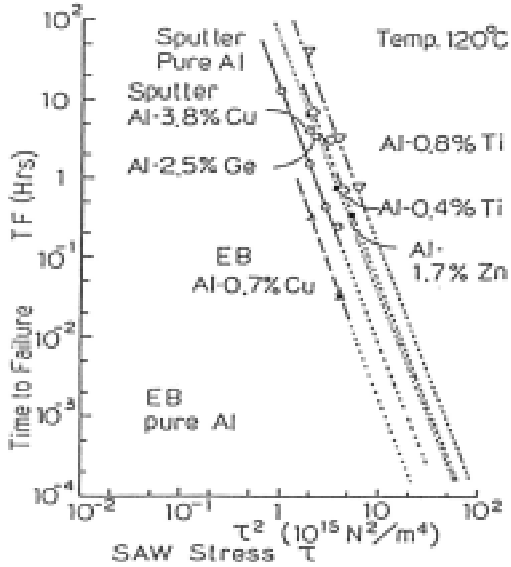


Fig.1 TF as a function of the SAW stress

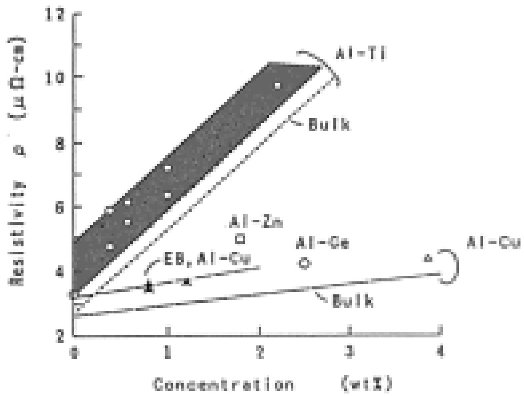


Fig.2 Electrical resistivity vs. film composition.

Structure and Property of Films

The durability of the SAW devices is influenced by the structure and properties of the electrode films, such as, the grain size, grain-boundary structure, clustering, texture (preferred orientation of the grain axis), presence of point defects, and residual static stress. Fig 3 shows the grain size in pure Al, Al+Ti, Al+Ge, Al+Zn, and Al+Cu films, as determined by transmission electron micrography (TEM), as a function of the additive concentration. This figure shows that sputterd and Al+Ti films have smaller grain sizes than EB evaporated films and Al+Cu films. With Ti or Cu addition, this figure also shows that a higher concentration produces smaller grain sizes. This tendency correlates with a higher durability, except in the case of Zn addition. In Fig. 4, the durability in respect of SAW power is shown in relation to the grain size. The SAW stress that is substituted for the durability in the vertical axis is the extrapolated value inducing the degradation in the electrodes at the same TF as that of EB pure Al films in Fig.1[6]. This stress moderately decreases as the grain size increases. However, the stress in EB evaporated Al films decreases drastically, to less than 10% of the extrapolated values[6]. Therefore, the grain size seems to contribute partially to the reduction in the stress and durability in EB evaporated pure Al films. Hence, static stress in the films is another possible origin of such a decrease. Fig. 5 shows the SAW stress in relation to the residual static stress. The static stress is measured by the change in the surface curvature of the disk substrates. It contains a contribution $(1.5\pm0.5)\times10^8$ N/m^2 caused by the thermal expansion difference between the film and the substrate. This figure shows that EB evaporated pure Al films have a large tensile stress, of the order of 10^9 N/m^2. This is larger than the SAW stress required for the degradation. However, Al+additive or sputtered pure Al films have approximately 10% less stress than EB evaporated pure Al films[6]. This larger static stress in evaporated pure Al films almost correlates with the shorter TF, as shown in Fig.1. In conclusion, it is shown that the electrode's durability in relation to SAW power is increased, not only by decreasing the diffusion coefficients of Al atoms (by the addition) but also by reducing both the static stress and the grain size.

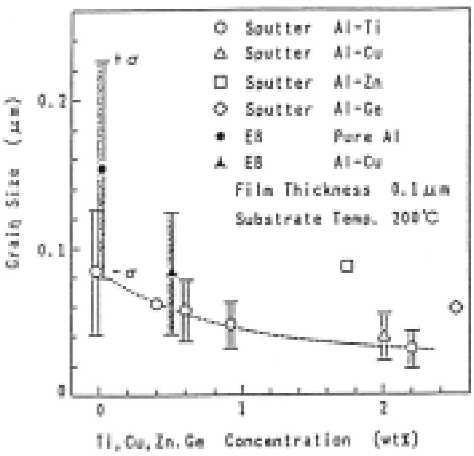


Fig.3 Grain size vs. film composition.

Dimension Control in High Power Al Electrodes

Here, dimension control using RIE is discussed for the fabrication of high-power durable SAW electrodes. Uniformity of the Al etch rate in a substrate is necessary for accomplishing precise pattern replication: a uniformity within ±5 % can be obtained except for the region within 5mm of the substrate edge. The etching is monitored through atomic Al emission (3961nm) from the plasma during RIE, and the endpoint is thereby detected, allowing control of the etching. For the Al+Ti electrodes, RIE with BCl_3 -containing gases can be more easily performed than in case of Al+Cu ones. Fig.6 shows the line width deviation of 1.2-micron Al+Ti electrodes, 0.1-micron thick. The deviation in the RIE is reduced to 56 % of that in wet etching, when the same resist A (Shipley-MP1350) is utilized.

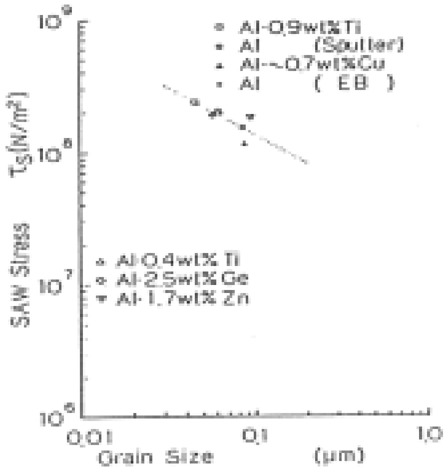


Fig.4 SAW stress as a function of grain size.

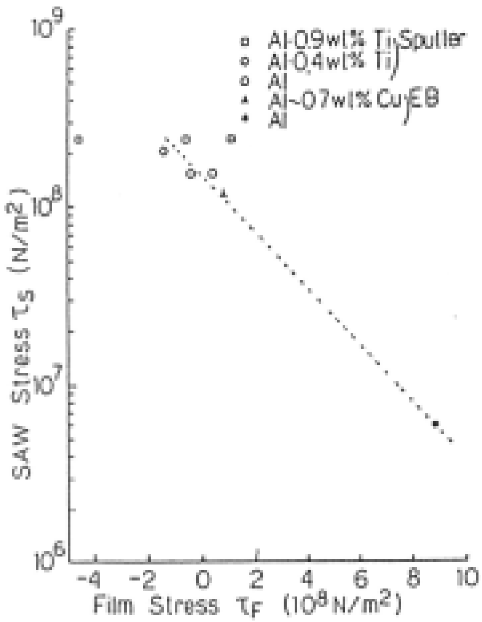


Fig.5 Stress and residual static stress in film.

Furthermore, by using dyed UV resist C(Tokyo Oka-TSMRCRB2), the deviation for RIE is reduced to the small value of 95nm. This is about 40 % of that for wet etching, and is rather smaller than that for RIE with deep-UV resist B(Fuji Hunt-FH6100). The cause of this reduction is that the side walls of the resist patterns tend to be more vertical. This suggests the importance of resist side wall, even in RIE of such thin Al films. Scanning electron micrographs (SEM) of the Al+Ti electrodes are shown in Fig. 7, compared to the electrode shapes replicated with RIE and with wet etching. It can be seen that the electrode produced by RIE (b) has a vertical side wall. This is in contrast to the case of wet etching (a), which gives a tapered side wall even in electrodes of thickness 0.1-micron. The figure also shows (c) electrodes finely replicated with deep-UV exposure and RIE.

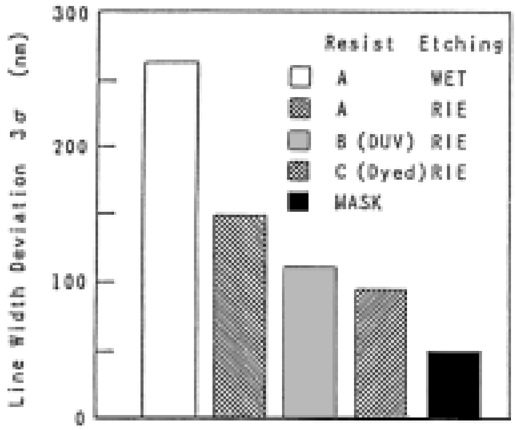
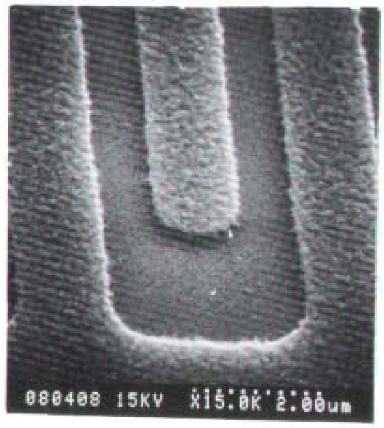
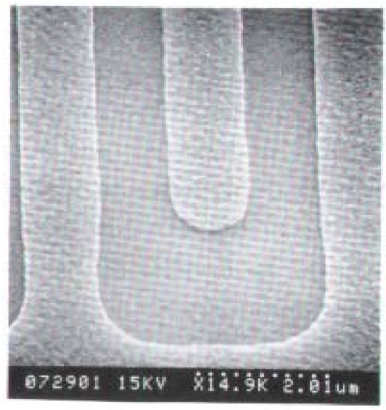


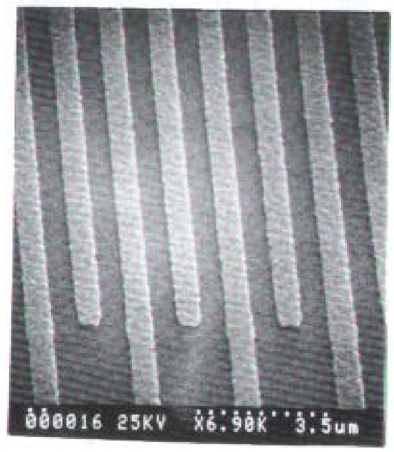
Fig.6 Line-width deviation of 1.2-micron Al+Ti electrodes, thickness 0.1-micron, Ti 0.4wt%.



(a) 1.2 micron, Wet Etching



(b) 1.2 micron, RIE



(c) 0.6 micron, Deep-UV/RIE

Fig7 SEM photos of Al+Ti electrodes, film thickness 0.1-micron on a $LiTaO_3$

Conclusion

The addition of different metals to Al electrodes has been discussed, in relation to high-power durability and fine dimensional control in high-frequency SAW devices. It has been shown that Ti addition is more effective than Ge, Zn or conventional Cu addition, in improving the durability. Furthermore, the durability in relation to SAW power is related to the reduction of the grain size and residual stress. Investigation of the fine-dimensional control reveals that the Al+Ti electrodes fabricated with a dyed UV positive-type resist and RIE (giving vertical walls) have a smaller electrode width deviation i.e., 40 % of that for conventional wet etching.

References

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