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Monitored vacuum deposition of dielectric coatings over surface acoustic wave devices

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ABSTRACT

We report on our experience in the control of magnetron sputtering process by in-situ monitoring of a surface acoustic wave (SAW) device (resonator or delay line) electrical response during the deposition of dielectric layers on the SAW device surface. While the electrical response changes with the growth of different layers, the response monitoring provides a useful feedback for layer thickness control in a multiple layer system. The monitoring approach is reproducible and gives physical insight into the SAW propagation changes occurring during the fabrication. It serves as a good tool for obtaining acoustic wave dispersion curves and helps in verifying theoretical and design principles of building multiple layer microwave acoustics devices.

1. Introduction

Surface acoustic wave (SAW) devices found wide application in standard communication systems as filters, resonators or delay lines. Moreover, because of their extreme sensitivity to external environments (temperature, strain, gas pressure), these devices are also widely used as sensors. In all these applications the technical development of SAW devices depends on advances in new design approaches and in new technological processes. Notably, in many modern devices coatings with dielectric layers are required. Some of them serve for modification of the physical properties of the devices such as the temperature coefficient of frequency (TCF), electromechanical coupling coefficient and/or acoustic velocity [1]. However, more important is the use of coatings for packaging of SAW devices, which cannot operate without protection of their surface from the environment. Known hermetic packaging techniques do not respond to all challenges, especially in the field of sensors that work at elevated temperatures (up to 1000 °C). Indeed constitutive components of standard sealed boxes can withstand a temperature up to about 250 °C. Thus, new packaging approaches need to be found. Coatings may serve for formation of acoustically isolated waves and thus they may replace additional packages for hermetically sealing the sensitive surface from the aggressive environment [2]; on the contrary, sensitivity-enhancing coatings work in chemical, biological and physicals sensors [3]. In some cases, very thin dielectric coatings can be used for monitored trimming of the working frequency of a SAW device [4]. In all such cases the coatings drastically change the properties of the SAW and thus of the actual devices, so that understanding and control of the incurred changes are required. Sometimes, analysis of the monitored deposition results allows making conclusions on the process parameters that lead to faults, such as layer delamination; introducing corrections at a specific stage improves the processing reliability. Besides, the in-situ monitoring of the thickness dependence of electrical properties provides dispersion characteristics of the waves as the natural output, thus becoming a powerful instrument for acoustic wave investigation. In this way, one can study some physical properties of deposited layers together with their dependence not only on the film thicknesses, but also on elastic and

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dielectric properties of materials in the specific thin film form. This paper summarizes the results obtained in several useful examples of monitoring application to different devices and different materials.

2. Equipment specific details

Usual SAW devices consist of thin-film metallic electrodes patterned into interdigital transducers (IDT) and in, some cases, Bragg reflectors on piezoelectric substrate surface. In mass production, the coatings are deposited on the surface of a single or multiple wafers. In-situ monitoring of the deposition process is more suitable for individual processing of a single device, however this single device may serve as a monitor sensor of batch processing. The processes used for film deposition may include vacuum evaporation, diode and magnetron sputtering, CVD and PECVD, and laser ablation deposition. Careful design of the measured test sample holder may allow depositing at elevated temperatures. Fig. 1 shows an example of vacuum chamber arrangement that requires a vacuum proof coaxial RF connector and low outgassing RF cable that withstands deposition conditions. For multiple ports measurement the number of cables and connectors increases accordingly. A SAW device is mounted on a substrate holder in a way to allow the deposition onto the required surface of the SAW device. In Fig. 1, a SAW device is mounted directly on a PC-board and wire bonded. However, packaged devices without lids can well be used in combination with different package fixtures.

Initial tests have proven that using vacuum thermal or e-beam evaporation and DC or RF (13.56 MHz or below) diode and magnetron sputtering does not induce damaging voltages in the circuit of a vector network analyzer (VNA) that measures the SAW device (at least in normal equipment operation regimes). The VNA cables may be calibrated with a corresponding calibration kit ("open", "short" and "load"). We mostly use self-made calibration tools with same PC-boards that are used as substrate holders, where a miniature 50 Ohm resistor and a short-circuiting wire replace the measured SAW device. With the calibration in this way, the accuracy of the measurements that can be estimated from the comparison of PC-board mounted device measurements with on-die measurements of the same SAW device with microwave probes. The microwave probes are calibrated with standard calibration kits. The measurement deviations usually do not exceed several percent, and this error is most often adequate for comparison with modeling results.

Additional effects requiring special care are related to heating of the monitoring device by the parts of the operating deposition equipment, such as the radiation from the evaporator or from hot areas of the sputtering target and from bombardment by ions or neutral particles accelerated in plasma. The temperature may reach values when solder melts, the PC-board laminate decomposes, and organic glues burn-out. In order to avoid the damage, the overheating can be controlled by periodically pausing the equipment operation with a process specific duty cycle. However another problem arises from high temperature sensitivity of acoustic wave velocity and thus of the high TCF up to 100 ppm/°C which results in the response central frequency variation with heating and cooling. In order to estimate the error induced by heating, the deposition process is switched-off (before reaching the required central frequency) for periods of about 30–90 min and the central frequency reading is taken. In addition, electrical cables inside the deposition chamber are wrapped with Al foil and shadow masks are made with foil over the sample holder. This arrangement determines the deposition window over the PC-board test sample holder and cable connections and serves for protection against excessive heating and from the deposits of sputtered materials on unwanted parts of the measurement circuits and of the equipment. With all these simple precautions, the processing becomes reliable, consistent and predictable.

3. Temperature compensation coating

A good example of thin film deposition over SAW devices is the SiO_2 coating for TCF reduction. This process has found a wide application in production of antenna duplexers for mobile communication [1,5]. When studying the complex behavior of the wave transformation the in-situ monitoring gives invaluable information for process optimization. It is especially important when a complex modal content of different kinds of acoustic waves is expected in particular structures. Among such systems, the structures utilizing longitudinal leaky SAW (LLSAW) demonstrate a very complex behavior of the response obtained with surface modification by SiO_2 layer.

For this experiment we prepared a synchronous resonator with 20 electrodes in the IDT and in each grating (100 nm gold on 5 nm Ti; with metallization ratio 50%) on YZ cut of $LiNbO_3$ with electrode pitch of 1.9 microns (IDT period – 3.8 microns). RF magnetron sputtering at 13.56 MHz from a SiO_2 target was used, while monitoring was performed with Agilent™ E5070a VNA by observation and registration of the resonator admittance. Time intervals between recordings of each response were registered thus giving an idea on the thickness of the growing layer. The final thickness of 1 micron was achieved after the last deposition run, so with total deposition time of 256 min and with time intervals registered we

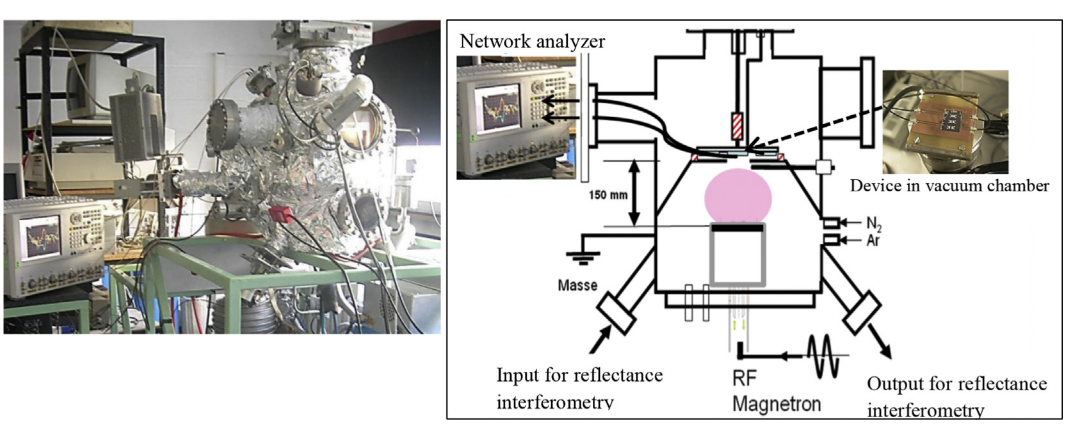

Fig. 1. Photo (left) and schematic presentation of the chamber setup (center) used for monitored deposition of thick AlN layers on delay lines connected to RF cables (right).