Current Status and Prospect of Surface and Bulk Acoustic Wave Devices for Mobile Communications

Ken-ya Hashimoto

Graduate School of Engineering, Chiba University
1-33 Yayoi-cho, Inage-ku, Chiba 263-8522, Japan

k.hashimoto@faculty.chiba-u.jp

This talk reviews current status and future prospect of radio frequency (RF) surface and bulk acoustic wave (SAW/BAW) devices used in mobile communications. Then a survey is given to demands imposed to these devices for realization of near future communication systemss.

Currently, numerous functions are embedded in a tiny IC, which enables to process vast data in digital domain with surprisingly high speed and extremely low power. IC industries have paid a lot of efforts to replace analog functions to degital ones as much as possible. But, until now, all trials were failed at least for the RF signal filtering, which is commonly realized by SAW/BAW technologies. Active and digital filters are not applicable for the purpose because generation of unnecessary signals must be suppressed completely.

As a result, performances of current mobile communications are often limited by those of RF SAW/BAW devices, and thus drastic enhancement of their performances is still strongly demanded in addition to further reduction of physical size and price. It is interesting to note that there may remain plenty of rooms for improvement although 50 years have been passed from the first proposal of SAW devices. In fact, everything is market driven.

What are demanded for near future? They are categorized into five items described below:

1. Residual Losses

Although current SAW/BAW filter and duplexers exhibit extremely high performances, there still remain unknown excess losses in addition to electrode ohmic loss, acoustic absorption and scattering. One possible mechanism is energy leakage to surroundings. We investigate how such leakage occurs using the full wave analysis and a behavior model, and try to find effective countermeasure(s) to overcome the problem. The laser probe system was developed to visualize the device resonance pattern, and is used for detailed investigation. We will show how the system is effective for the diagnosis of RF SAW/BAW devices.

2. Temperature Stability

Most of all materials become soft with the temperature *T* rise. Then the filter passband of RF SAW/BAW devices shifts downward with *T*. In some frequency bands, allowed fluctuation range of the filter passband is extremely narrow, and thus the temperature compensation (TC) is necessary. RF SAW/BAW devices are often integrated with RF power amplifiers, and their heat exhaust also causes the passband fluctuation. Thus TC is the one of the hottest topics in the SAW/BAW area. TC is realized by the use of SiO_2 as a member of the device structure. This is owing to its unique feature, i.e., it becomes stiff with *T*. It should be noted that since SiO_2 is not piezoelectric, thinner SiO_2 is better from the other aspects. It is well known that SiO_2 properties including the temperature coefficient of elasticity (TCE) change drastically with the material preparation, however it was unclear which material property is related to the TCE. We pointed out that the TCE is well characterized by the FTIR spectra, which can be used as a guideline to search “excellent” SiO_2 films for SAW/BAW devices. We also showed that fluoride doping in SiO_2 offers further TCE improvement.

There is another technique to realize TC SAW devices, the wafer bonding. After a piezoelectric wafer such as $LiNbO_3$ and $LiTaO_3$, is bonded with a stiff substrate like sapphire, the piezoelectric wafer is thinned by polishing. Due to stress caused by the bimorph effect, TCE is improved. In contrast to the SiO_2 deposition, the wafer bonding scarcely influences to the other performances.

3. Nonlinear Signals

Introduction of new communication schema like orthogonal frequency division multiplex (OFDM) and carrier aggregation (CA) always makes requirements given to RF SAW/BAW devices tougher and tougher. One example is the linearity. Although SAW/BAW devices are quite linear, further reduction of nonlinearity is demanded. There are two questions: "(1) where and how does the nonlinearity occur?" and "(2) how do we measure extremely weak signals?" We investigate these two issues in collaboration with a company. Our strategy is development of a behavior model for this case and comparison with the experiment. We will show how well the nonlinearity behavior is understood until now.

4. Power Durability

Duplexers for pico-cell baseband stations may expand applicability of SAW/BAW devices. For such application, not only the linearity but also the power durability are critical. Again, there are two questions: "(1) where and how does the failure occur after exposure to high RF power?" and "(2) how do we measure the mean time to failure of these devices?" We investigate the latter issue in collaboration of SAW/BAW industries all over the world so as to establish an international standard as the IEC activity.

5. New materials

Achievable performances of these devices are inherently limited by the choice of the piezoelectric material. Three important parameters are the electromechanical coupling factor K^2, acoustic wave velocity V, and the temperature coefficient of frequency (TCF). Thus the SAW/BAW community is always looking for new exotic materials, device structures and/or fabrication processes extending applicability of RF SAW/BAW technologies.

From this aspect, we pay much attention on paraelectric Sc doped AlN films offering anomalously strong piezoelectricity and low acoustic and dielectric losses in the GHz range. ScAlN films can be deposited to a large area by reactive sputtering. Thus ScAlN seems to be applicable to wideband and low loss SAW devices operating over 3 GHz, which current technologies may not be feasible. This material is also paid much attention for the use in RF BAW devices to expand their application area.

Piezoelectric materials with low acoustic wave velocity and/or large dielectric constant are also demanded for realization of small size SAW duplexers operating in relatively low frequencies. However, no practical solution could be found until now.

Ken-ya Hashimoto was born in Fukushima, Japan, on March 2, 1956. He received his B.S. and M.S. degrees in electrical engineering in 1978 and 1980, respectively, from Chiba University, Japan, and his Dr. Eng. degree from Tokyo Institute of Technology, Japan, in 1989.

In 1980, he joined Chiba University as a Research Associate, and is now a Professor of the University. For 2013-2015, he was the Director of the Center for the Frontier Science, Chiba University.

In 1998, he was a Visiting Professor of Helsinki University of Technology, Finland. In the winter of 1998/1999, he was a Visiting Scientist of the Laboratoire de Physique et Metrologie des Oscillateurs, CNRS, France. In 1999 and 2001, he was a Visiting Professor of the Johannes Kepler University of Linz, Austria. He was a Visiting Scientist of the Institute of Acoustics, Chinese Academy of Science, Beijing, China in 2005/2006. For 2009-2012, he was a Visiting Professor of the University of Electronic Science and Technology of China, Chengdu, China.

In 2001, he served as a guest co-editor of the IEEE (Institute of Electrical and Electronics Engineers) Transactions on Microwave Theory and Techniques (MTT) Special Issue on Microwave Acoustic Wave Devices for Wireless Communications, and a publicity co-chair of the 2002 and 2015 IEEE International Ultrasonics Symposia. He was appointed to a member of the speaker's bureau of the IEEE MTT Society. He also served as an International Distinguished Lecturer of the IEEE Ultrasonics, Ferroelectrics, and Frequency Control (UFFC) Society from 2005 to 2006, an Administrative Committee (ADCOM) Member of the IEEE UFFC Society from 2007 to 2009 and from 2014 to 2016, a Distinguished Lecturer of IEEE Electron Device Society from 2007 to 2009, and a general co-chair of the 2011 and 2018 IEEE International Ultrasonics Symposia. In 2015, he received the Ichimura Industrial Award from the New Technology Development Foundation for "Development of Optimal Substrate 42-LT for Radio Frequency Surface Acoustic Wave Devices".

His current research interests include simulation and design of various high-performance surface and bulk acoustic wave devices, acoustic wave sensors and actuators, piezoelectric materials and RF circuit design.

Dr. Hashimoto is a Fellow of IEEE, and a Member of the Institute of Electronics, Information and Communication Engineers of Japan, the Institute of Electrical Engineers of Japan, and the Acoustical Society of Japan.