3J1-1

Development of high intensity and high frequency ultrasonic transducers using piezoelectric films

圧電性結晶膜を用いた高周波強力超音波トランスデューサの開発とその評価

Mutsuo Ishikawa[1†], Ayaho Tsukamoto[1], Nao Saito[1], Akito Endo[2], Shintaro Yasui[3], Marie Tabaru[3], Hiroshi Funakubo[3], Minoru Kurosawa[3]

([1] **Toin Univ. of Yokohama,1 [2]Kishu Giken Kogyo CO., ltd.2, [3]Tokyo Institute of Technology3**)

石河睦生１[1†]，塚本絢穂２[1]，齋藤 直３[1]遠藤聡人４[2]，安井伸太郎５[3]，田原麻梨江６[3]，舟窪 浩７[3]，黒澤 実８[3]，([1]桐蔭横浜大１，[2]紀州技研２，[3]東工大３)

1. Introductions

Recently, high-frequency ultrasonic transducers are proposed for some applications using piezoelectric crystal such as ultrasonic cleaners, actuators or acoustic inkjet printing devices. For high power radiations of ultrasound in water at high frequency, it is important to have higher limitation of vibration velocity of thickness mode with high piezoelectric constant of piezoelectric films. However it is difficult to fabricate piezoelectric films with quite satisfactory characteristics of it.

Therefore we investigate high power piezoelectric and ultrasonic characteristics of piezoelectric films. Thus, the $KNbO_3$ films were deposited by hydrothermal method[1,2)]. It is known that the hydrothermal method is able to fabricate high quality piezoelectric films. In this study, we measured sound pressures and acoustic radiation pressures at resonant frequency with prototype high-frequency ultrasonic transducer using thickness mode of hydrothermal $KNbO_3$ films.

2. Deposition of piezoelectric $KNbO_3$ films.

The $KNbO_3$ films were grown at 240 ºC on $(100)_c$ Nb-$SrTiO_3$ substrates by the hydrothermal method. An autoclave (PARR, 4748) that contained an inner vessel made of Teflon to resist high alkali solutions was utilized for the hydrothermal growth. A 20 m*l* solution of 10 mol/*l* KOH (Kantokagaku) and 1.0 g of niobium oxide powder (Nb_2O_5, purity 99.95%, Kantokagaku) were used as source materials of K and Nb, respectively. The $(100)_c$ Nb-$SrTiO_3$ substrate was kept facing down with a Teflon folder in the inner vessel, and the above-mentioned source materials were mixed and placed in the autoclave. The autoclave was shut tight and placed in a constant-temperature oven (Yamato DS-400) maintained at 240 ºC for a hydrothermal chemical reaction. The $KNbO_3$ thick films on The $(100)_c$ Nb-$SrTiO_3$ were obtained with repetition of above reaction. After deposition, also piezoelectric powders remained in aqueous solution of Teflon vessel.

The lattice constants of the substrate was 3.9 Å and the lattice constants calculated from each sprit peaks were found to be approximately 4.03 to 4.06 Å. Therefore it is considered that the compression stress was occurred on boundary of $KNbO_3$ and substrate with that the $KNbO_3$ films were peeled from substrate easily using week mechanical stress by ultrasonic pressure. The $KNbO_3$ thick films by hydrothermal method with repetition of deposition. In this study, a concave type hydrothermal $KNbO_3$ films were deposited for focusing type ultrasonic transducers such as Fig.1.

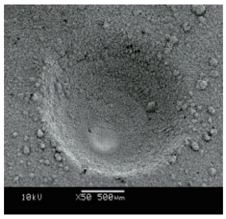

Fig.1 Surface of piezoelectric $KNbO_3$ films with concave shape

3. Fabrication of ultrasonic transducers using $KNbO_3$ films

Prototype high frequency and high intensity ultrasonic transducers using the $KNbO_3$ films were prepared such as Fig.2.

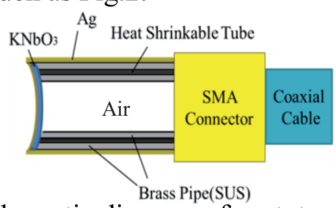

Fig. 2 Schematic diagram of prototype ultrasonic transducers with $KNbO_3$ of concave shape.

The back side of active area of ultrasonic transducers have air structures and SMA connectors that are used for high frequency driving. The air structure is a backing material for the purpose of ultrasonic reflection to front of apertures. The piezoelectric $KNbO_3$ films are covered by electrode. And the electrode is connected to signal line and grand line respectively.

4. Experimental results and conclusions

The radiated ultrasound at resonance frequency was measured by kept hydrophone in degassed water. The hydrophone was maintained at front face of the prototype ultrasonic transducers in degassed water. The radiated ultrasound was determined at receiving sensitivity of the hydrophone. Additionally the signal was utilized burst waves in this measurement. Figure 3 shows the resonance frequency of the prototype $KNbO_3$ ultrasonic transducers of focusing type that measured by hydrophone.

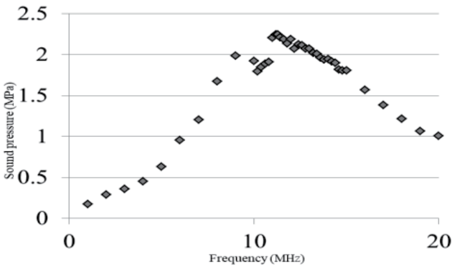

Fig.3 Relationship between driving frequency and radiated sound pressure using prototype ultrasonic transducers.

Broad peaks of thickness mode appeared at approximately 11 MHz. Also, the quality factor of the resonance frequency was approximately 3. The driving voltage was arbitrarily value that was utilized for measurement of resonance frequency. Figure 4 shows result of measurement of the radiated sound pressure. Also, the radiated sound pressure has a linearity relationship between the applied voltages until 3 MPa. And the maximum pressure was approximately 4MPa or more.

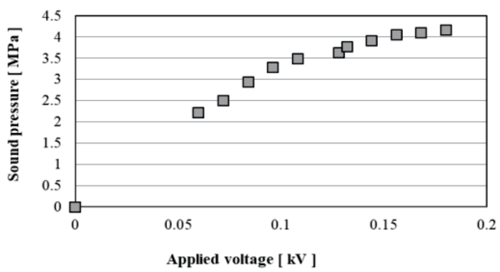

Fig.4 Relationship between signal voltages and radiated sound pressure with prototype ultrasonic transducers.

This value is very high ultrasound and enough value for several high intensity ultrasonic applications. Additionally, the 4MPa was limit due to our set up. The reason of the delimitation for measurement under 4MPa being that the durability limit of the hydrophone or cavitation occurred on ultrasonic propagation area by high intensity ultrasonic radiation.

And then, a relatively rapid rectilinear acoustic streaming[3)] was appeared. A laminar velocity was approximately 4mm/s in water. Therefore an acoustic radiation pressure from prototype ultrasonic transducer was calculated by the formula of $P_r^2 = 2\rho c^2 \eta U/\alpha r^2$ as proof of high intensity ultrasonic radiation. Where ρ is density of degassed water, c is sound speed of water, η is coefficient of viscosity of water, r is diameter of aperture of transducer, α is attenuation constant of water and U is laminar velocity of an appearance acoustic streaming in this experiment. The resultant acoustic radiation pressure was 230kPa.

Subsequently, a nozzleless acoustic inkjet device was manufactured by this prototype high frequency and high intensity ultrasonic transducers using the $KNbO_3$ films. This device ejects droplets from the liquid surface of $Pb(NO_3)_2$ aq by high intensity and high frequency ultrasonic radiations. Figure 5 shows a photograph and XRD patterns of surface of deposited crystals of $Pb(NO_3)_2$ on glass surface.

a) b)

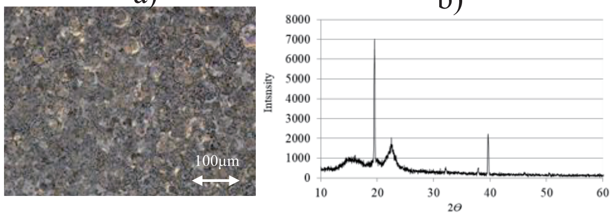

Fig.5 a) surface photograph and b) XRD patterns of deposited $Pb(NO_3)_2$ on glass by nozzleless acoustic inkjet device with prototype ultrasonic transducers using concave $KNbO_3$ films.

High intensity and frequency ultrasonic transducers were developed by hydrothermal concave $KNbO_3$ films. To conclude, the $KNbO_3$ thick films by hydrothermal method is able to utilize for the device of ultrasonic treatment such as requiring high intensity ultrasonic radiation.

Acknowledgment
This work was supported by JSPS KAKENHI Grant Number 15K21460, 17K01427 and the Cooperative Research Project of
Research Center for Biomedical Engineering.

References
1. M. Ishikawa, K. Yazawa, S. Yasui, T. Fujisawa, T. Hasegawa, T. Yamada, T. Morita, M. Kurosawa, and H. Funakubo: Jpn. J. Appl. Phys. **48** (2009) 09KA14
2. M. Ishikawa, H. Einishi, M. Nakajima, T. Hasegawa, T. Morita, Y. Saijo, M. Kurosawa, H. Funakubo. Jpn. J. Appl. Phys., 49, (2010)07HF01
3. M. Tabaru, T. Azuma, K. Hashiba, Jpn. J. Appl. Phys., 49, (2010) 07HF09-1