CHAPTER 6

CONCLUSIONS AND SUGGESTIONS FOR FURTURE WORK

6.1 Conclusions

6.1.1 $LiNbO_3 \cdot SiO_2$ glass and glass-ceramic system

The appearance of glasses with the compositions (100-*x*)$LiNbO_3 \cdot xSiO_2$ (with x = 10, 20, 25, 30, 35, 40, 45, 50, 55 and 60) as prepared by the incorporation method were light yellowish transparent for $20 \leq x \leq 35$ while that of glasses with x = 10 or $x \geq 40$ were at least partly opaque under the conditions supplied. As shown by TEM micrographs, replicas phase separation occurred and SiO_2-rich droplets in a $LiNbO_3$-rich matrix phase were formed. The size of the droplets increased with increasing SiO_2 content.

Transparent glass-ceramic samples with $20 \leq x \leq 35$ could be obtained by heat treatment of temperature up to 600 °C. They all contained ferroelectric rhombohedral $LiNbO_3$ crystals. Heat treatment at 650 °C resulted in samples with slight light scattering while the heat-treated samples at ≥ 700 °C were opaque. The mean crystallite sizes of the $LiNbO_3$ crystals are in the range of 14 to 50 nm (calculated by Scherrer equation) and 36 to 446 nm (SEM micrographs) as increased with increasing heat treatment temperature and SiO_2 content of the sample. The crystallite sizes by calculation were smaller than that of the SEM micrographs about 2-3 times. The relative permittivity was in the range of 75 to 190, which increased with increasing heat treatment temperature. But the relative permittivity decreased with increasing frequency and SiO_2 content. Table 6.1 compares the dielectric constant of the glass-ceramics from this research with other relative works. For the first time, transparent $LiNbO_3$ glass-ceramics with SiO_2 content as small as 20 mol% were prepared.

Optical and electrical properties of crystalline phases are related to the microstructure features which are resulted from the glass composition and heat-treatment conditions. The measured values of transmittance (%) and relative permittivity show that the obtained transparent glass-ceramics, based on $LiNbO_3$ crystals, can be considered as a good ferroelectric material.

Table 6.1 Comparison of relative permittivity values at room temperature and 1 kHz of the glass samples in this research with others nearly research.

Glass systems	**Dielectric constant (ε_r) at 1 kHz**
$LiNbO_3 \cdot SiO_2$	101 (35 mol% SiO_2) - 119 (25 mol% SiO_2)
$LiNbO_3 \cdot SiO_2 \cdot Al_2O_3$	54 (55 mol% SiO_2) - 325 (15 mol% SiO_2)
$Li_2O \cdot Nb_2O_5 \cdot SiO_2$ [103]	102 (34 mol% SiO_2)
$Li_2O \cdot Nb_2O_5 \cdot B_2O_3$ [104]	19 (60 mol% B_2O_3)

6.1.2 $LiNbO_3 \cdot SiO_2 \cdot Al_2O_3$ glass system

Nanocrystallization of monophasic $LiNbO_3$ was demonstrated in a reactive glass system of (95-*x*)$LiNbO_3 \cdot xSiO_2 \cdot 5Al_2O_3$ where $15 \leq x \leq 55$ by the incorporation method. The $LiNbO_3$ crystals having sizes less than 100 nm with different morphologies are successfully embedded in the glass matrix. The optimum composition of these glasses were found at 35 mol% SiO_2 as they contain homogenous size of $LiNbO_3$ nano-crystals and are also mechanically robust and translucent. The relative permittivity was in the range of 25 to 325. They decreased with increasing SiO_2 content and increasing frequency. These glass samples also offer optimum value of relative permittivity and low loss.

6.2 Suggestions for future work

The process for the preparation of transparent glasses, especially large samples was rather difficult, due to the narrow glass forming region of these systems. Most of the quenched samples were easily devitrified and sensitive to the processing conditions, such as atmosphere, ambient temperature, quenching speed, composition, type of mould, glass samples thickness and annealing temperature, etc. Therefore, it is necessary to fully understand, search and control suitable conditions and compositions for making transparent base glasses.

In this study, the transparent glass-ceramics containing nano-sized $LiNbO_3$ crystals are successfully produced. However, other additional properties, especially opto-electrical properties have not yet been investigated. This could be a concentration of future works. The manner in which these properties vary as a function of temperature, frequency and electric field determining the suitability of materials for specific applications could also be studied. Moreover, optical properties of materials are of interest to sciences, engineers and technologists, those generally of greatest concern to users of transparent glass-ceramics including birefringence, nonlinear effects, photosensitive and color measurement.