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Electrical characteristics of high power piezoelectric transformer for 28 W fluorescent lamp

Juhyun Yoo[a,*], Kwanghee Yoon[a], Sangmo Hwang[a], Sungjae Suh[b], Jongsun Kim[c], Chungsik Yoo[c]

[a]*Department of Electrical Engineering, Semyung University, 390-711 Jechon, Chungbuk, South Korea*
[b]*Institute for Industrial Technology Research, Hannam University, Hannam, South Korea*
[c]*Samsung Electro-Mechanics Co. Ltd., Suwon, Kyungki-Do, South Korea*

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Abstract

In order to drive the T5 fluorescent lamp developed recently, contour vibration mode piezoelectric transformers with the composition of $Pb(Ni_{1/2}, W_{1/2})O_3$–$Pb(Mn_{1/3}, Nb_{2/3})O_3$–$Pb(Zr, Ti)O_3$ (PNW–PMN–PZT) were fabricated to the modified filter structure. The composition ceramics were consolidated to the square plate using cold isostatic pressing and the ring/dot electrodes were designed on it for the impedance matching of the fluorescent lamp. Electrical properties and characteristic temperature rise caused by the vibration were measured. Efficiencies of the transformers proved to be above 90%. A 28 W fluorescent lamp was successfully driven by all of the transformers. The transformer with ring/dot electrode ratio of 1.83 showed the best properties in terms of output power, efficiency and characteristic temperature rise, 30.95 W, 97.5% and 8.3°C, respectively.

Keywords: Fluorescent lamp; Piezoelectric transformers; Luminous efficiency

1. Introduction

The conventional fluorescent lamps with 32 mm tube diameter are replaced with smaller one to conserve lamp materials and increase luminous efficiency. Currently 32 W lamps with 26 mm in diameter are used for such purpose. For more improvement in efficiency, again 32 W lamps can be converted to recently developed T5, which has tube diameter of 16 mm [1]. Application of slim lamps, however, requires small sized electronic inverters to fulfil the design philosophy of miniaturization. The inverter we focus on in this study is the piezoelectric transformer utilized as a driving source for general fluorescent lamps. In fact, application of the transformer has been limited to low power liquid crystal display (LCD) backlight (2−3 W) [2] and not been tried for high power class LCD backlight of 6−10 W or general fluorescent lamps. The purpose of this study is to develop high power piezoelectric transformer and to investigate electrical properties of the transformer in driving a 28 W fluorescent lamp, T5. As far as the electrical characteristics are concerned, the conventional Rosen-type transformers [3] are not properly used for fluorescent lamp application because of high output voltage and low current. For low voltage and high current application, the contour vibration mode piezoelectric transformers with $Pb(Ni_{1/2}, W_{1/2})O_3$–$Pb(Mn_{1/3}, Nb_{2/3})O_3$–$Pb(Zr, Ti)O_3$ (PNW–PMN–PZT) composition have been developed. It has been shown that a 14 W fluorescent lamp had been successfully driven using the transformers. In the ring/dot-type transformers, the mechanical vibration caused by the ac voltage applied to the ring electrode is transferred to the output dot electrode and finally converted voltage proportional to the induced vibration. Higher energy conversion efficiency can be obtained from this structure because the electromechanical coupling coefficient, k_p, in planar mode is higher than the coefficient, k_{31}, in length extensional mode [1,4]. In addition, input and output electrical energy can be effectively increased by the increased input and output capacitance. Moreover, in the structure of ring/dot electrode, electrode gap between input and output was rounded to improve the insulation between input ring electrode and output dot electrode. In this experiment, to drive a 28 W lamp, contour vibration mode piezoelectric transformers were fabricated using PNW–PMN–PZT composition ceramics. For the density and strength

* Corresponding author. Tel.: +82-43-649-1301; fax: +82-43-648-0868.
E-mail address: juhyun57@chollian.net (J. Yoo).

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enhancement, cold isostatic pressing (CIP) was utilized. The electrical properties of the fabricated transformers were investigated as well as the lamp driving characteristics of the transformers.

2. Experiment

PNW–PMN–PZT system ceramics with the following composition were used for the high power contour-vibration-mode piezoelectric transformer.

$$Pb(Ni_{1/2}, W_{1/2})O_3{-}Pb(Mn_{1/3}, Nb_{2/3})O_3{-}Pb(Zr, Ti)O_3$$

The composition was selected primarily because of its high dielectric constant and mechanical quality factor, Q_m. The plate type transformers with the size of 31.5 mm × 31.5 mm × 2.5 mm were fabricated via conventional mixed oxide process and cold isostatic pressing. The specimens investigated in this study have different ring/dot area ratios as listed in Table 1. Fig. 1 shows schematic diagrams of piezoelectric transformer and experimental set-up, respectively. The poling treatment toward thickness direction was carried out in a 120°C silicon oil bath at the electric field of 25 kV/cm for 30 min. Resonant and anti-resonant frequencies of the transformers were measured using HP4194A impedance analyzer. The capacitance was determined with the LCR meter, ANDO 4304. The effective electromechanical coefficient (k_{eff}), mechanical quality factor (Q_m) and output impedance (Z_{out}) were calculated using the following equations:

$$k_{eff} = \sqrt{\frac{f_a^2 - f_r^2}{f_a^2}} \quad (1)$$

$$Q_m = \frac{1}{2\pi f_r(1 - (f_r/f_a)^2)RC} \quad (2)$$

$$Z_{out} = \frac{1}{2\pi f_r C_{out}} \quad (3)$$

where f_r and f_a are resonant and anti-resonant frequencies, and R and C are resonant resistance and capacitance measured at 1 kHz, respectively. C_{out} represents the capacitance of the dot part terminal. The electrical properties and 28 W lamp driving characteristics of the piezoelectric transformers were evaluated using oscilloscope, Tektronix TDS3054, and current probe, Tektronix TCP202. Characteristic temperature rise caused by the vibration during lamp driving was also measured with the infrared thermometer, Reytex MX2.

Table 1
Specifications of piezoelectric transformer

	P1	P2	P3	P4
X (mm)	17	18	19	20
Y (mm)	20	21	22	23
Ring/dot area ratio	2.99	2.54	2.16	1.83

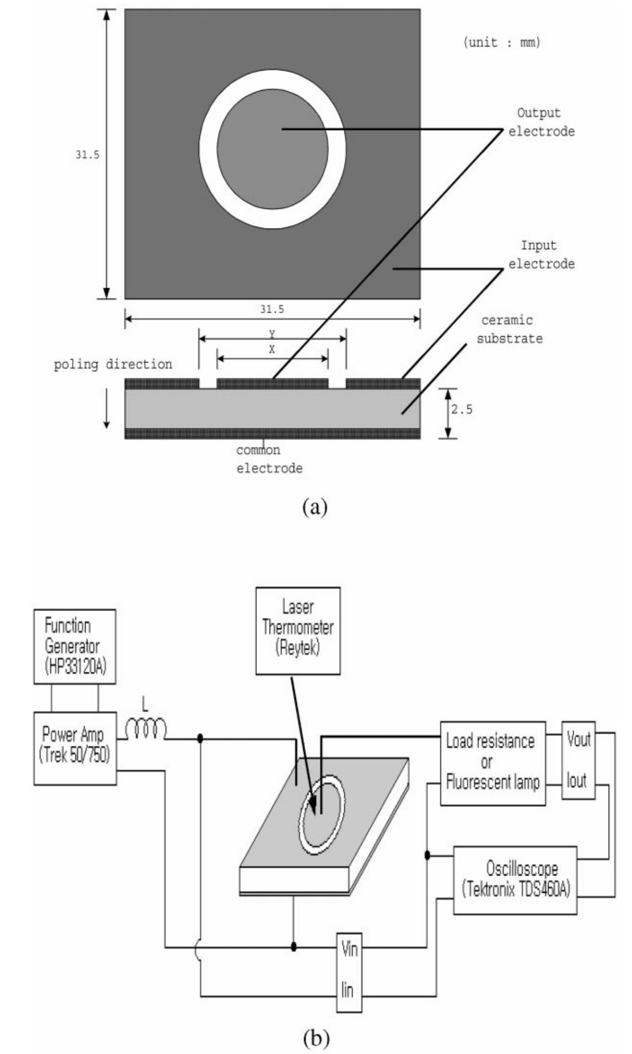

Fig. 1. Schematic diagrams of piezoelectric transformer and experimental set-up.

3. Results and discussion

The physical and piezoelectric properties of PNW–PMN–PZT ceramics are listed in Table 2. As can be seen, the high

Table 2
Physical properties of PNW–PMN–PZT

Density (g/cm^3)	7.68
Dielectric constant	1680
k_P	0.523
Q_m	1.814
E_c (kV/cm)	9.15
T_c (°C)	272
Grain size (μm)	4.09
−20 to 80°C (TCf_r) (ppm/°C)	88