Advanced Materials '93, I / B: Magnetic, Fullerene, Dielectric, Ferroelectric,
Diamond and Related Materials, edited by M. Homma et al.
Trans. Mat. Res. Soc. Jpn., Volume 14B

Pulsed laser ablation using vibrating PZT target.

J. Frantti, H. Moilanen and S. Leppävuori

Microelectronics and Material Physics Laboratories, University of Oulu,
P.O. Box 400, FIN-90571 Oulu, Finland

Laser ablation using a XeCl-excimer laser and a vibrating target has been studied. The purpose in using the vibrating target was to investigate the effects of an alternating displacement on the ablation process and the piezoelectric effects of the impulse of the laser beam pulse on the piezoelectric target.

The target material was neodymium doped PZT (PNZT) and it was integrated to a vibrating PNZT layer driven from an ac voltage source. The target and the vibrating layer were prepared by pressing and firing PNZT powder. Integration of layers was achieved by using an electrode paste between layers. A simple PNZT layer was also used to study the effects of the XeCl laser beam on to the target.

The impedance and the displacement of the target were measured as a function of the frequency of the driving voltage. The theoretically calculated radial frequency of the target was found to fit well to both the impedance resonance frequency and to the frequency of oscillation of the voltage generated by the laser pulses. No specific effect was observed in film growth rates due to the vibrating PZT target.

1. INTRODUCTION

Laser ablation has been found to be a suitable method for producing stoichiometric lead zirconate titanate (PZT) thin films [1, 2]. High energy short time laser pulses also have a piezoelectric effects on a PZT target. Such pulses have a high momentum which induces an easily measurable piezoelectric effect. This suggests an investigation into whether the converse piezoelectric effect can influence the ablation process. This idea is based on the fact that piezoelectric material can exhibit very high acceleration values and, because laserpulses melt the surface of the target, it seems possible that this melted material would experience acceleration to a noticeable degree.

2. EXPERIMENTAL

2.1. Laser ablation system

The laser ablation system consisted of a vacuum chamber with a quarz window port and an electrical feedthrough which was used to vibrate the target and to measure the voltage generated by the laser pulse from the target electrodes.

Pulsed laser ablation was performed using an XeCl excimer laser (wavelength 308nm, pulse energy 50mJ, pulse duration 20ns) in a vacuum (pressure $5x10^{-5}$ mbar). The partly focused excimer laser beam was scanned over the target held at an angle of 90 degrees to the beam.

2.2. Targets and measurement arrangements

The target material used was $Pb_{0.97}Nd_{0.02}(Zr_{0.55}Ti_{0.45})O_3$ powder, which was pressed to the shape of a bar and then sintered for ten minutes at temperature of 1100°C in a lead atmosphere and subsequently polished. Two kinds of targets were used, both having a diameter of 16.5 mm. The first target was a simple 2.6 mm thick bar with thick film printed AgPd electrodes, Figure 1. The target was polarized with 6 kV voltage and was used for measurements carried out at atmospheric pressure with a very low laser fluence to avoid surface damage. The second target had a 3 mm thick unpoled layer and a second 3 mm thick poled layer, as shown in Figure 1. This target was constructed to eliminate a possible pyroelectric effect caused by laser pulses in the poled layer and to generate a target surface having a high acceleration value. During ablation a driving voltage of 120 V_{pp} with frequencies up to the resonance frequency of 125 kHz was used to vibrate the second target. The impedance of the targets as a function of frequency was measured using a Hewlet Packard network analyzer and voltage measurements were made using a Hewlet Packard digital oscilloscope. For displacement measurements as a function of a Michelson interferometer system was used [3].

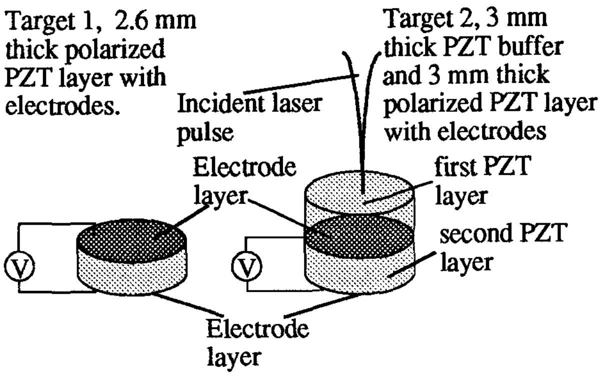

Figure 1. Schematic picture of the targets used to determine the piezoelectrical effect caused by a XeCl excimer pulse.

3. RESULTS AND DISCUSSION

If we suppose that the position of the target surface $z(t)$ is moving sinusoidally as a function of time and if we neglect effects due to the electrodes, the mass of the unpoled part of the target etc. we can write the following equations for the position $z(t)$, velocity and acceleration of the target surface:

$$z(t) = A_0 \sin(\omega t) \tag{1}$$

$$\frac{\partial z(t)}{\partial t} = \omega A_0 \cos(\omega t) \tag{2}$$

$$\frac{\partial^2 z(t)}{\partial t^2} = -\omega^2 A_0 \sin(\omega t) \tag{3}$$

where $f = \omega/2\pi$ is the oscillation frequency of the input voltage (valid if we assume that the piezoelectric target, thickness l, can follow it), $A_0 = l\, d_{33} E_3$ (= 3 mm 223×10^{-12}C/N*20kV/m) is the maximum amplitude generated by the voltage, d_{33} is the piezoelectric constant and E_3 is the electric field along the z-axis. For maximum acceleration at a resonance frequency of 127 kHz we obtain from the equation (3) an estimated value of 8.5 km/s^2.

The voltage induced by the laser pulses was measured for both targets and was found to be due to the piezoelectric effect. The voltage had a resonance at an impedance resonance frequency, which in this is case the same as the resonant frequency f_R of radial vibration given by [4]

$$f_R = \frac{R_1}{2\pi r} \sqrt{\frac{1}{\rho (1 - \sigma^2) s_{11}^E}} \tag{4}$$

where σ is Poisson's ratio, r the radius of the target, ρ the density, s_{11}^E the elastic compliance at constant field and R_1 is the first root of the equation $R J_0(R) = (1 - \sigma) J_1(R)$, where J_0 and J_1 are Bessel functions of order 0 and 1 respectively. If σ is 0.30 then R_1 is 2.049. Substituting for σ = 0.30, r = 8.25 mm, $s_{11}^E = 13.8 \times 10^{-12}$ m^2/N and ρ = 7560 kg/m^3 we obtain from the equation (4) for f_R a value of 128 kHz. Now the measured main resonance (minimum impedance) was at a frequency of 127 kHz corresponding to the maximum displacement measured by the Michelson interferometer system, and the voltage response was oscillating at a frequency of 127 kHz for the target 2.

The main resonance for the target 1 was at a frequency of 128 kHz and the voltage response was oscillating at 129 kHz. Figures 2, 3, 4 and 5 show the impedance as a function of frequency and the voltage as a function of time induced by laser pulses for both targets. Figure 4 also shows the displacement of the target 2 as a function of frequency.

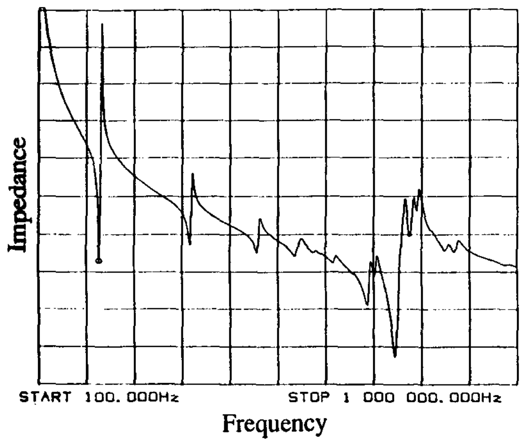

Figure 2. Impedance (in arbitrary units) versus frequency for the target 1. The horizontal frequency scale is 99900 Hz/div.

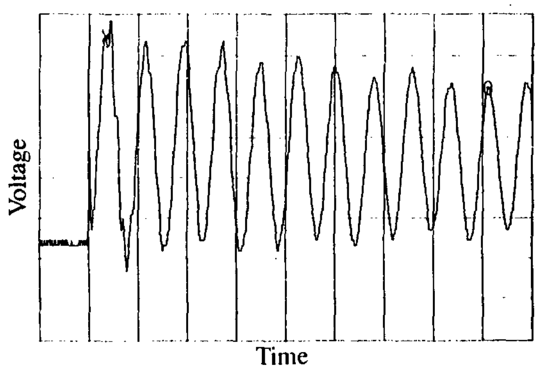

Figure 3. Voltage response caused by a XeCl excimer pulse as a function time for the target 1. The horizontal time scale is 10.0 µs/div. The vertical scale is 500 mV/div.

Experiment using a Q-switched Nd:YAG laser was also done with a wavelentgh 1064 nm, pulse repetation rate 200 Hz and peak power 64 kW. It was found that the main effect of the laser pulses on to the target was due pyroelectric effect and the second and weaker effect was due piezoelectric effect.

Attemps to determine differences in film growth rates during ablation by measuring with a growth rate monitor were made but no specific effect was observed.

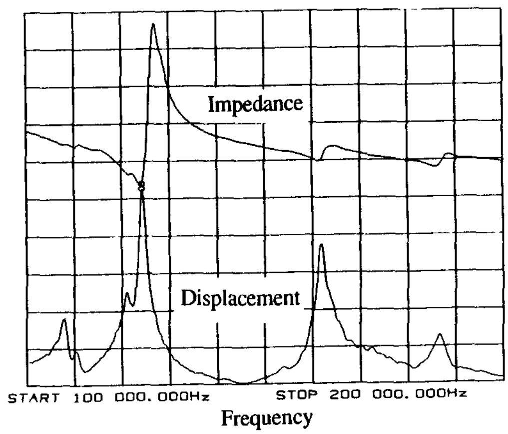

Figure 4. Impedance measured by a network analyzer and displacement (in arbitrary units) measured by the Michelson interferometer system as a function of frequency for the target 2. The horizontal frequency scale is 10000 Hz/div.

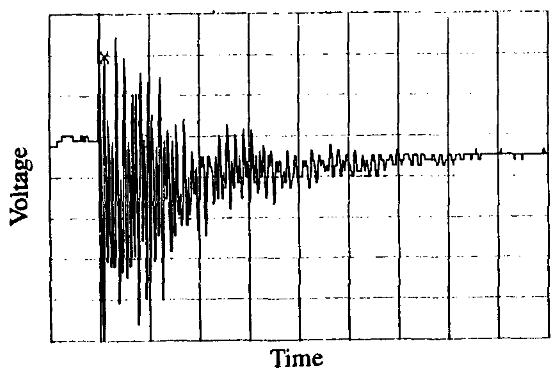

Figure 5. Voltage response caused by a XeCl excimer laser as a function time for the target 2. The horizontal time scale is 100 µs/div. The vertical scale is 12.5 mV/div

4. CONCLUSIONS

It has been found that laser pulses have a clear and well determined piezoelectric effects on the PZT target. It was noticed that the resonance frequencies of impedance and mechanical displacement have a clear connection.

It seems that the oscillating surface of the target has no measurable effect on film growth rates during ablation. However, this work may lead to a detector for measuring the energies of laser pulses.

REFERENCES

1. H. Zhang, H. Moilanen, A. Uusimäki, S. Leppävuori and R. Rautioaho, Journal of Electronic Materials, 22 (1993) 425.
2. J. Frantti, H.Moilanen, S. Leppävuori and A. Uusimäki, Mat. Res. Soc. Symp. Proc. 285 (1993) 415.
3. H. Moilanen, S. Leppävuori, A. Uusimäki, Proc. of 3rd Int. Conf. on New Actuators, (1992), 196
4. W. P. Mason and H. Jaffe, Pro. of the IRE 42 (1954).