REPORT DOCUMENTATION PAGE

Form Approved
OMB NO. 0704-0188

1. AGENCY USE ONLY (Leave Blank)	2. REPORT DATE 1 Mar 03	3. REPORT TYPE AND DATES COVERED Final Report 1 Jul 01 – 30 Sept 02

4. TITLE AND SUBTITLE

Material issues in uncooled ferroelectric infrared detectors

5. FUNDING NUMBERS
C
DAAD19-01-1-0689

6. AUTHOR(S)

Judy Wu

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
University of Kansas Center for Research
2385 Irving Hill Road
Lawrence, KS 66045-7563

8. PERFORMING ORGANIZATION REPORT NUMBER
FED26810

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)

U. S. Army Research Office
P.O. Box 12211
Research Triangle Park, NC 27709-2211

10. SPONSORING / MONITORING AGENCY REPORT NUMBER

42807.1-EL

11. SUPPLEMENTARY NOTES

The views, opinions and/or findings contained in this report are those of the author(s) and should not be construed as an official Department of the Army position, policy or decision, unless so designated by other documentation.

12 a. DISTRIBUTION / AVAILABILITY STATEMENT

Approved for public release; distribution unlimited.

12 b. DISTRIBUTION CODE

13. ABSTRACT (Maximum 200 words)

The overall goal of this 12-month project was to explore ion beam assisted growth of uncooled ferroelectric thin film infrared detectors so as to improve the material properties and thus device performance of thin film ferroelectric (TFFE) infrared imaging components/systems. Two issues were addressed. One is to optimize physical properties of the ferroelectric layer, aiming at improving sensitivity and reducing noise of these devices. The other is to grow the whole multilayered TFFE at a low thermal budget below 500 °C, which is required for a monolithic TFFE on Si-based readout integrated circuits. Ion beam assisted deposition (IBAD) was employed in this research as it can preferentially generate a textured growth pattern, and provide atoms with extra kinetic energies, promoting formation of high-quality oriented ferroelectric films at low substrate temperature. During the project period, two vacuum systems were constructed/modified for the proposed research. One was addition of ion beam to our existing pulsed laser deposition system for ion beam assisted deposition (IBAD-PLD) and the other was the new thermal/e-beam co-evaporator equipped with IBAD and high-resolution electron diffraction capabilities (IBAD-TEC). Growth of samples was conducted on both systems and the experimental results are summarized in the report.

14. SUBJECT TERMS	15. NUMBER OF PAGES 7
	16. PRICE CODE

17. SECURITY CLASSIFICATION OR REPORT	18. SECURITY CLASSIFICATION ON THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	UL

NSN 7540-01-280-5500

Standard Form 298 (Rev.2-89)
Prescribed by ANSI Std. 239-18
298-102

Material issues in uncooled ferroelectric infrared detectors

FED26810 Final Report
March 1, 2003

PI Name: Judy Wu
PI Address: Dept. of Phys., Univ. of Kansas, Lawrence, KS 66045
PI phone: (785) 864-3240
PI fax: (785) 864-5262
PI email: JWU@KU.EDU

1. Summary of Research and Education activities

This 12-month (August 1, 2001 through July 31, 2002) grant from US Missile Defense Agency (MDA) supported one graduate student and one PI (Judy Wu) summer month. An additional 3-month no-cost extension was requested for completion of the project. The overall goal of the project is to explore ion beam assisted growth of uncooled ferroelectric thin film infrared detectors so as to improve the material properties and thus device performance of thin film ferroelectric (TFFE) infrared imaging components/systems. Two issues were addressed. One is to optimize physical properties of the ferroelectric layer, aiming at improving sensitivity and reducing noise of these devices. The other is to grow the whole multilayered TFFE at a low thermal budget below 500 ˚C, which is required for a monolithic TFFE on Si-based readout integrated circuits. Ion beam assisted deposition (IBAD) will be employed in this research as it can preferentially generate a textured growth pattern, and provide atoms with extra kinetic energies, promoting formation of high-quality oriented ferroelectric films at low substrate temperature. During the project period, two vacuum systems were constructed/modified for the proposed research. One was addition of ion beam to our existing pulsed laser deposition system for ion beam assisted deposition (we call it IBAD-PLD system in the following) and the other was the new thermal/e-beam co-evaporator equipped with IBAD and high-resolution electron diffraction capabilities (IBAD-TEC). Growth of samples was conducted on both systems and the experimental results are summarized in the following. This project involved collaboration with Raytheon Infrared Technology (Dallas), the Oak Ridge National lab and Los Alamos Lab. The details of the experimental results can be found in our papers (1 published, 1 submitted and several in preparation).

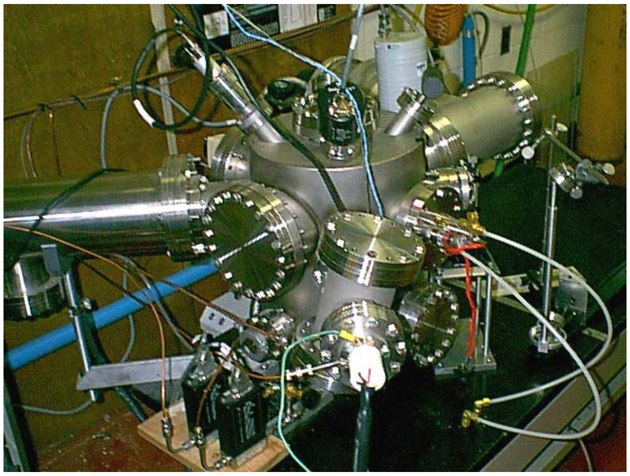
One graduate student, Mr. Ronald Vallejo, and one visiting scientist, Dr. Sangho Yun, were supported partially during the project period. Mr. Ronald Vallejo has obtained Ph.D. candidacy recently and is currently working on his Ph.D. thesis. Dr. Yun is affiliated to The Royal Institute of Technology, Sweden and his visit to the University of Kansas resulted in several publications and long-term collaboration between the two institutions. In addition, our laboratory has also participated many outreach activities including University Open House, Parents Day, Science Fairs, many other laboratory tours for K-12 students organized by KU.

2. Major Research Results

■ <u>Construction/modification of IBAD-PLD and IBAD-TEC systems</u>

During the project period, two vacuum systems were constructed/modified for the proposed research. One was the addition of the ion beam (an 8 cm Kaufman source) to our existing pulsed laser deposition system for ion beam assisted deposition and Fig. 1 shows a picture of this IBAD-PLD system. This ion source is directed at 45 degree to the normal of the sample and ions of many different elements can be generated from this ion source for IBAD.

We have also built a new thermal/e-beam co-evaporator equipped with IBAD and high-resolution electron diffraction capabilities (IBAD-TEC), as shown in Fig. 2.



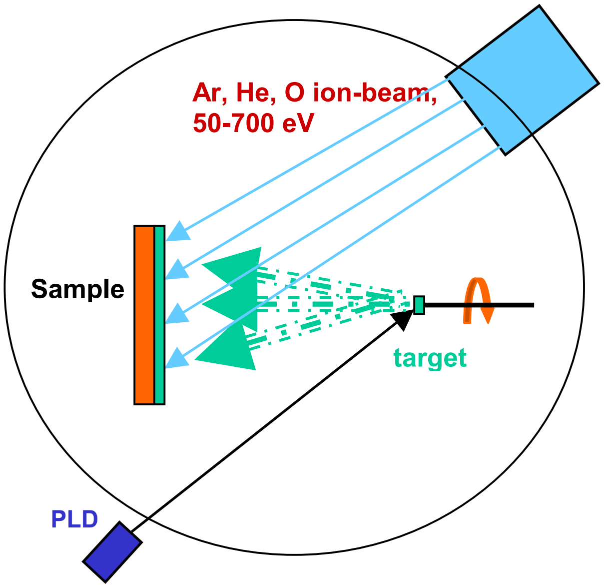


Fig. 1 Pictures (upper) and schematic (lower) of the IBAD–PLD system modified during the project.

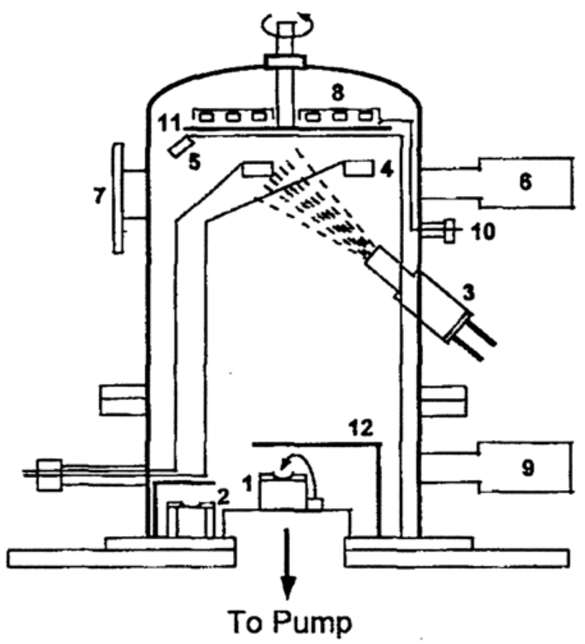


Fig. 1 Pictures (upper) and schematic (lower) of the IBAD e-beam evaporation system constructed under this DURIP fund. In the lower panel, 1—e-gun; 3—ion source; 11—substrate facing down; 6—RHEED gun; and 7—RHEED screen port.

Research enabled by the PLD-IBAD and IBAD-TEC systems is two folded in this project. At low ion beam energies, the ion beam provides an extra kinetic energy to the growing surface of the film, resulting in a reduced thermal energy required for epitaxy of the films. This may reduce the thermal budget required for the TFFE devices. At high ion beam energies, the ion beam can preferentially sputter off certain grains under growth, leaving others that having their main crystalline axes aligned with the ion beam incidence direction. This can generate textured growth on non-textured substrates.

■ <u>Growth of TFFE on IBAD textured templates</u>

PZT, like many other perovskites, is highly anisotropic. Growth of these films along selected orientations, such as the c-axis orientation for PZT, can optimize the performance of the devices and this can only be achieved on textured substrates. Unfortunately, the sacrificial layers employed now in industry are amorphous polymers that can be easily removed with standard plasma etching. It is, however, impossible to build single-crystal-like (epitaxial) TFFE detectors on top of this amorphous layer in conventional thin films growth processes. In fact, most PZT films reported on non-textured substrates are, to the best, polycrystalline. This results in degraded ferroelectric effect, and increased noise levels due to the existence of large-angle grain boundaries. A fundamental question one may ask is whether it is possible at all to grow highly textured film on a non-textured substrate. The answer to this question is very important not only to the TFFE-related devices, but also many other thin film devices when the substrates cannot provide an appropriate matrix for high-quality epitaxy of the desired thin films. Growth of high-

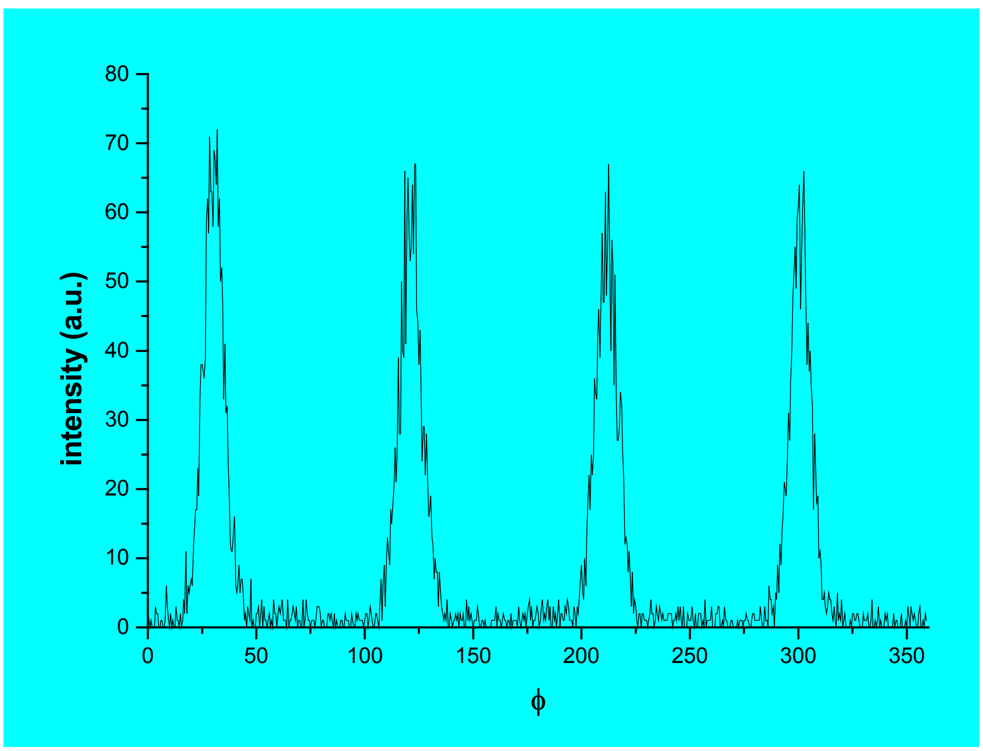


Fig. 3. XRD ϕ–scan of the IBAD MgO layer confirmed that the IBAD MgO is epitaxial (001) oriented. The thickness of the MgO is about 10 nm.

quality epitaxial ferroelectric films with optimized ferroelectric properties at low thermal budget therefore presents a major challenge in development of high-performance uncooled TFFE IR detectors as well as in fundamental materials sciences. We have employed IBAD textured MgO template for growth of c-oriented PZT. MgO has perfect lattice match with PZT and is also chemically compatible. Using the IBAD-TEC system, a 10 nm thick (001) oriented MgO epi template was first made on Si/SiOx or polymer coated Si substrates. The x-ray diffraction ϕ–scan confirmed that the IBAD MgO layer is epitaxial (see Fig. 3) and the TFFE grown on top of it showed c-axis orientation (Fig. 4).

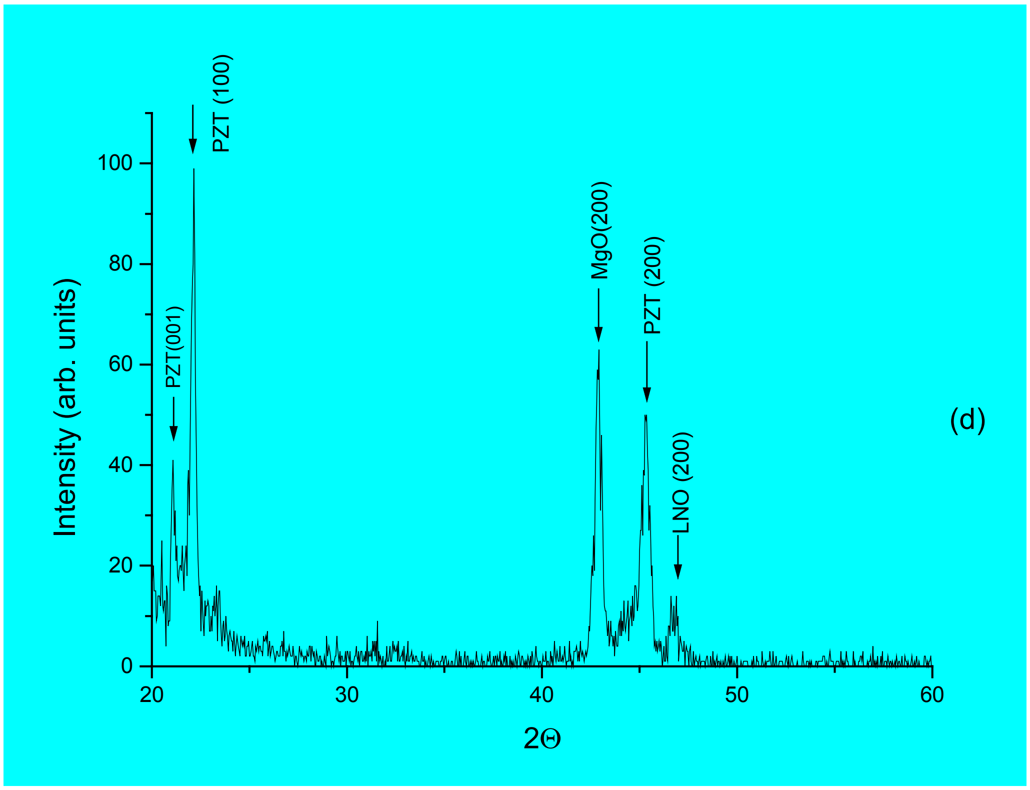


Fig. 4. X ray diffraction pattern of grown ferroelectric capacitor (PZT/LNO/IBAD-MgO/Si) by Pulsed Laser Deposition.

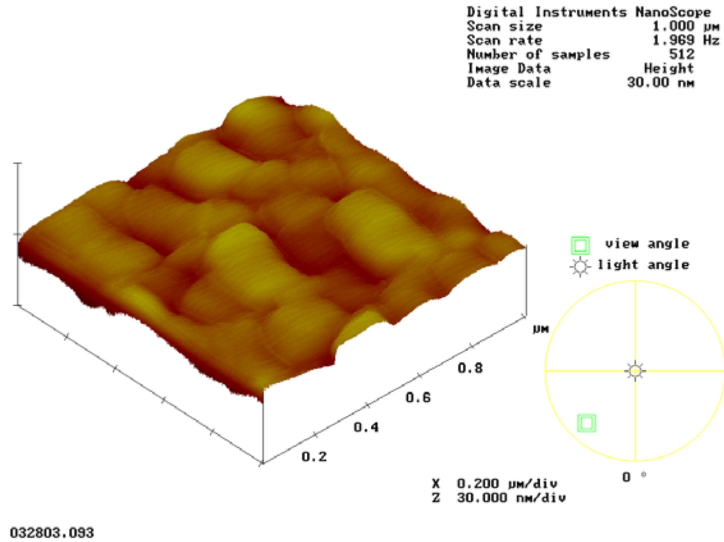


Fig. 5. Surface morphology images taken by AFM of the PZT layer of Ferroelectric capacitor grown on LNO/IBAD-MgO/Si. The LNO layer was grown by PLD and the PZT layer was grown by IBAD - PLD.

■ Low temperature growth of TFFE

For the applications of uncooled Infrared-detector, synthesis efforts have focused on mono-layer $PbZr_{0.28}Ti_{0.72}O_x$ (PZT) and bi-layer $PbZr_{0.28}Ti_{0.72}O_x$ / $LaNiO_3$ (PZT/LNO) thin films onto $LaAlO_3$ substrates. There are two approaches to the highly oriented thin film synthesis at certain

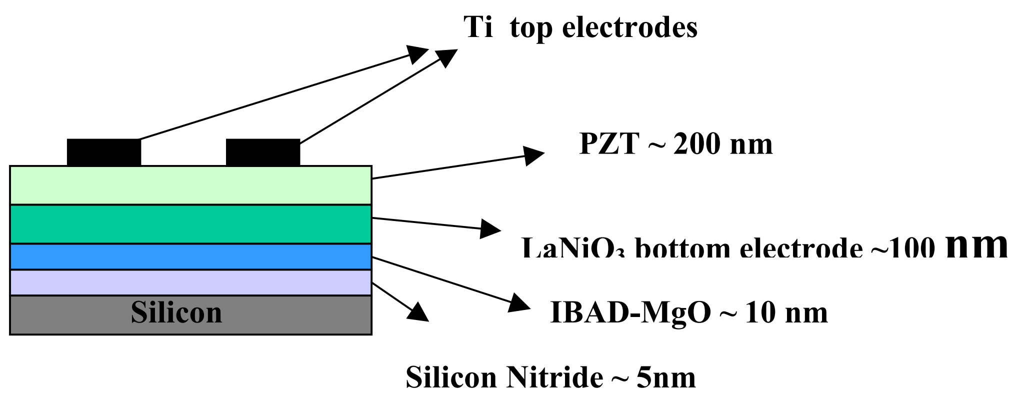


Fig. 6. Schematics of samples for ferroelectric measurement.

the directions; those employing conventional Pulsed Laser Deposition (PLD) and Ion-Beam-Assisted Pulsed Laser Deposition (IBAPLD). In order to investigate the effect of ion-beam on growth of the thin film aforementioned, the comparison between two approaches have been made by varying growth parameters and fixing low total pressure (0.1~0.3mTorr); temperatures and ion-beam energies. The highly *c*-axis oriented PZT thin films have been successfully grown on $LaAlO_3$ substrates at 400ºC using IBAPLD in a ion-beam energy range of 20-80 eV (Ar^+), while the higher temperature (> 450ºC) is needed by PLD. It implies that the growth temperature of PZT thin film can be lowered by more than 50ºC using ion-beam source. However, the preferred orientation of the films is poor above 100eV of ion-beam energy. On the other hand, multi-layer (PZT/LNO) thin films have also been prepared at 450ºC by PLD, having highly *c*-axis orientation with respect to substrates and will be continued to prepare using IBAPLD. The ferrolectric measurement of these samples were characterized using our in–house LCR meter for the capacitance and tangent loss at frequency of 100 Hz and 1 kHz. In general, the low-temperature grown TFFE has either comparable (T above 500 C) or degraded (T is lower than 500 C) performance compared to that grown at higher temperature (~ 650 C). This indicates that the kinetic energy provided by the ion beam is not adequate to compensate the thermal energy by heating. Future experiments will be focused on optimizing ion beam energy and current.

Related Publications:

1. S.H. Yun, R. Vallejo, J.Z. Wu, M. Tidrow, H. Braaten and C. Hansen, "Systematic investigation of the growth of $LaNiO_3$/PZT/$LaNiO_3$/Si and $LaNiO_3$/PZT/$LaNiO_3$/polymer/Si for IR-detector applications", to appear in Proceeding of SPIE Aerosense Conf. Orlando, April 1-5, 2002.
2. J.Z. Wu, R. Vallejo, S.H. Yun, M. Tidrow, H. Braaten, C. Hansen, and P. Adrent, "Effect of in-plane and out-of-plane misorientation on the ferroelectric properties of thin film ferroelectric PZT infrared sensors on Si substrates", submitted to Proceeding of 2003 SPIE AeroSense Conference, Orlando, April 20-24, 2003.