Magnetic resonance properties of all solution-processed Iron Garnet thin flms

Thesis submitted in the partial fulfillment for the Award of Degree

Doctor of Philosophy

By

Rajnandini Sharma

SCHOOL OF MATERIALS SCIENCE AND TECHNOLOGY
INDIAN INSTITUTE OF TECHNOLOGY
(BANARAS HINDU UNIVERSITY)
VARANASI - 221005
INDIA

Roll No. 18111007

2024

Declaration

I, **Rajnandini Sharma**, certify that the work embodied in this thesis is my own bona-fide work and carried out by me under the supervision of **Dr. Shrawan Kumar Mishra** from July 2018 to December 2023 at the **School of Materials Science & Technology**, Indian Institute of Technology (BHU), Varanasi. The matter embodied in this thesis has not been submitted for the award of any other degree/diploma. I declare that I have faithfully acknowledged and given credits to the research scholars/scientists wherever their works have been cited in my work in this thesis. I further declare that I have not willfully copied any others' work, paragraphs, text, data, results, etc., reported in journals, books, magazines, reports dissertations, thesis, etc., or available at websites and have not included them in this thesis and have not cited as my own work.

Date 29 July 2024

Place: Varanasi

Signature of the student

(Rajnandini Sharma)

Certificate by the Supervisor

It is certified that the above statement made by the student is correct to the best of my knowledge.

29/07/2024

Dr. Shrawan Kumar Mishra
School of Materials Science & Technology
Indian Institute of Technology (BHU), Varanasi

Associate Professor/सह-आचार्य
School of Materials Science & Technology/पदार्थ विज्ञान एवं प्रौद्योगिकी स्कूल
Indian Institute of Technology/भारतीय प्रौद्योगिकी संस्थान
(Banaras Hindu University), Varanasi/काशी हिन्दू विश्वविद्यालय, वाराणसी

Coordinator
School of Materials Science & Technology
Indian Institute of Technology (BHU), Varanasi

Coordinator/समन्वयक
School of Materials Science & Technology/पदार्थ विज्ञान एवं प्रौद्योगिकी स्कूल
Indian Institute of Technology/भारतीय प्रौद्योगिकी संस्थान
(Banaras Hindu University), Varanasi/काशी हिन्दू विश्वविद्यालय, वाराणसी

Dedicated to Maa

CERTIFICATE

This is to certify that the revised thesis entitled "Magnetic resonance properties of all solution Processed Iron Garnet thin films" is being submitted by Mr./Ms/Mrs Rajnandini Sharma in partial fulfillment for the award of Ph.D. in Department /School of...M.S.T.......IIT(BHU), Varanasi is a record of bonafide work carried out by him/her.

Date of Submission: 27.06.2024

(Supervisor)

(Co-supervisor)
(If any)

Forwarded by:

HoD/CoS
(Signature with Seal)

Coordinator/समन्वयक
School of Materials Science & Technology/पदार्थ विज्ञान एवं प्रौद्योगिकी स्कूल
Indian Institute of Technology/भारतीय प्रौद्योगिकी संस्थान
(Banaras Hindu University),Varanasi/काशी हिन्दू विश्वविद्यालय, वाराणसी

Certificate

It is certified that the work contained in the thesis titled **"Magnetic resonance properties of all solution-processed Iron Garnet thin films"** by **Ms. Rajnandini Sharma**, Roll Number **18111007**, has been carried out under my/our supervision and that this work has not been submitted elsewhere for a degree.

It is further certified that the student has fulfilled all the requirements of Comprehensive Examination, Candidacy and SOTA for the award of Ph.D Degree.

SKmishra
29/07/2024

Supervisor
Dr. Shrawan Kumar Mishra
School of Materials Science & Technology
IIT (BHU), Varanasi-221005

Associate Professor/सह-आचार्य
School of Materials Science & Technology/पदार्थ विज्ञान एवं प्रौद्योगिकी स्कूल
Indian Institute of Technology/भारतीय प्रौद्योगिकी संस्थान
(Banaras Hindu University), Varanasi/काशी हिन्दू विश्वविद्यालय, वाराणसी

Copyright Transfer Certificate

Title of the Thesis : **Magnetic resonance properties of all solution-processed Iron Garnet thin films**

Name of the Student : **Rajnandini Sharma**

Copyright Transfer

The undersigned hereby assigns to the Indian Institute of Technology (Banaras Hindu University) Varanasi all rights under copyright that may exist in and for the above thesis submitted for the award of the **Doctor of Philosophy**.

Date 02/01/2024 Signature of the student

Place: Varanasi (Rajnandini Sharma)

Note: However, the author may reproduce or authorize others to reproduce material extracted verbatim from the thesis or derivative of the thesis for author's personal use provided that the source and the Institute's copyright notice are indicated.

Acknowledgements

First of all, I am very thankful to Balaji and Lord Shiva for their constant blessings and mental support that helped me overcome all the odds. I am also grateful to the holy city Kashi for its positive vibrations and spiritual driving force. It is a great honor to acknowledge the moral & scientific support, encouragement, and guidance that I have received from different research groups and several individuals at various places and institutions during the completion of my Ph.D. thesis. Without their advice, guidance, and friendship, this work would have indeed suffered. I believe success is a collective phenomenon that you achieve with the help of many individuals. Here I am gone; name those who helped me achieve my doctorate degree successfully. I am very grateful to my Ph.D. supervisor Dr. Shrawan Kumar Mishra, for his constant efforts and for being the person who supported me in this complete Ph.D. journey. Sir, you have helped me grow independentally and taught me how to work as a team member. You have also provided me opportunities to develop my technical skills, and I sincerely hope to continue learning from you. I am thankful to my lab members Dr. Shyam Babu, Raman, Nidhi, and Niti, and Simran for their moral support. Specially, I would like to thank Pawan for his suggestions. I am also appreciative of M.Tech. students (Shantanu, Rohit, Akash, and Rakesh, Arkapravo, Abhas, and Omkar) of the Quantum Lab, School of Materials Science and Technology, IIT (BHU) for their stimulating discussions and teaching me the balance between research and life.

I am thankful of the Dr. V. R. Reddy, Dr. R. J Choudhary, and Prof. S. Bhunia for experimental facility of UGC-DAE CSR, Indore and RRCAT, Indore. I am also thankful toward Dr. R. Rawat for his honest advice to have something in backup for the thesis. I am also grateful of Rathore sir, and Anil sir, engineers of UGC-DAE CSR indore for the experiments perform by them. I am thankful to Shivam and Rijul sir my co-authors for the nice feedback on the article. I would like to show gratitude towards Dr. B. Bhoi for the fruitful discussions.

I express my sincere indebtedness to Dr. E. G. Rini and Dr. Y. Choyal with deepest regards and profound respect for inspiring me for research. I also wish to express my indebtedness to Dr. Vasant Sathe, Scientist, UGC-DAE CSR, Indore, for supervising me during my M.Sc. dissertation, which builds a foundation in the arena of science.

I specially acknowledged the support of the SMST and CIF (Central Instrumental Facility), IIT BHU, Varanasi, and all its Techn. & Non-Techn. staff who have worked day and night to make this research work successful. I would also like to acknowledge all the faculty members Prof. D. Pandey, Prof. R. Prakash, Prof. P. Maiti, Dr. (Mrs.) C. Rath, Dr. A. K. Singh, Dr. C. Upadhyay, Dr. B. N. Pal, Dr. S. Singh, Dr. A. K. Mishra, Dr. N. Kumar, Dr. R. Kumar, and Dr. A. Kumar of SMST, IIT (BHU), for their direct and indirect guidance. Without the facilities, equipment, and raw materials provided by SMST, this thesis work would have remained a dream. I also wish to thank the authority of INSPIRE fellowship, Department of Science and Technology, India, for providing me with the necessary permission and financial assistance for conducting this thesis work. In SMST, I have honestly enjoyed the company of Nisha, Aakansha, Priya ma'am, Priyanka, Neha, Sapna, Urvashi, Pooja ma'am, Rajnikant, Prince, Anuraag, Vipin, Sunayana, and Rajlakshmi who always been present with me to accomplish my degree fruitfully. I am also thankful to Sanjay sir for introducing this institute to me.

I am thankful towards Pravin for always motivating me and believing in my potentials. I also like to thank my friends Varsha, Shubhangi, Vivek, Saroj ma'am, Kamakshi ma'am, Noshin, Asmita, and Ankit for listening to me and constantly encouraging me throughout my Ph.D. tenure.

I would also like to thank my research progress evaluation committee (RPEC) members, Dr. Shrawan Kumar Mishra (Chairman &, Supervisor), Dr. Sandip Chatterjee (External Expert, Dept. of Physics, IIT (BHU)), Dr. Bhola Nath Pal (Internal Expert) not only for their time and extreme patience but also for their thoughtful comments and suggestions. Thank you!

In the end, I would like to thank my mothers Mrs Saroj Sharma and late Alka Sharma and my brother Vasudev for their constant love, support and always stand stiff for me. I am also grateful to my father Mr. Chandrashekhar Sharma, my sister Divyanjali Sharma, my masi Mrs. Champa Jangir and my mamiji Mrs. Nirmala Jangir and Mrs. Sapna Jangir for there support in this endeavour. I would like to express my thank to all my extend family for there constant support and believing in me to achieve my dreams.

List of figures

List of tables

List of Abbreviations

YIG	Yttrium Iron Garnet
TmIG	Thulium Iron garnet
GGG	Gadolinium Gallium Garnet
FMR	Ferromagnetic Resonance
XRD	X-ray Diffraction
XPS	X-ray Photoelectron Spectroscopy
AFM	Atomic Force Microscopy
SEM	Scanning Electron Microscopy
MPMS	Magnetic Property Measurement System
SQUID	Superconducting Quantum Interference Device
VSM	Vibrating Sample Magnetometry
JCPDS	Joint committee on powder diffraction standards
FCC	Field Cooled Cooling

XRR	X-ray Reflectivity
FMI	Ferromagnetic Insulators
PLD	Pulsed laser Deposition
LPE	Liquid Phase Epitaxy
GIXRD	Grazing Incident X-ray Diffraction
FCW	Field Cooled Warming
SOC	Spin-orbit Coupling
PMA	Perpendicular Magnetic Anisotropy
MOKE	Magneto-optic Kerr Effect

List of Symbols

Å	Angstrom
λ	Wavelength
nm	Nanometer
μm	Micrometer
M_{eff}	Effective Magnetization
M_S	Saturation Magnetization
K_U	Uniaxial Anisotropy Constant
K_S	Shape Anisotropy Constant
K_σ	Stress-induced Magnetic Anisotropy
H_U	Magnetic Anisotropy Field
σ	Stress
$\Delta\varepsilon$	Lattice Mismatch
(hkl)	Miller indices
α	Gilbert's Damping parameter
ΔH_0	Inhomogeneous Dissipation factor
γ	Gyromagnetic ratio