Analysis of nanometer-thin yttrium iron garnet (YIG) films on a 3-inch wafer scale

C. Dubs[1], O. Surzhenko[1], A. Hertzsch[1], A. Gopakumar[1], B. Heinz[2], D. Mandic[3], C. Hirschle[4], J. Xu[1], T. Reimann[1], M. Lindner[1], P. Pirro[2]

[1] INNOVENT e.V. Technologieentwicklung, Jena, Germany, [2] Rheinland-Pfälzische Technische Universität Kaiserslautern-Landau, Kaiserslautern, Germany
[3] Filmetrics, KLA Corporation, Unterhaching, Germany, [4] Bruker Nano GmbH, Berlin, Germany

Quality inspection of yttrium iron garnet films

Comparison of 3-inch wafers grown in the same and different series

→ To access the structural perfection, uniformity and reproducibility of critical properties of nanometer-thin YIG films across 3-inch wafers
→ To establish their suitability as a platform for future nanoscale spin-wave circuits [1,2]

Topographical analysis

→ Film thickness mapping (micro X-ray fluorescence, optical reflectance)
→ Film roughness analysis (atomic force microscopy (AFM))
→ Defect density mapping (optical microscopy)

Microwave analysis

→ Spin mixing conductance measurements on Pt/YIG bilayers

The challenge

→ Ensuring high-quality assessment of YIG films at the 3-inch wafer scale
→ Achieving results comparability through standardized analytical methods

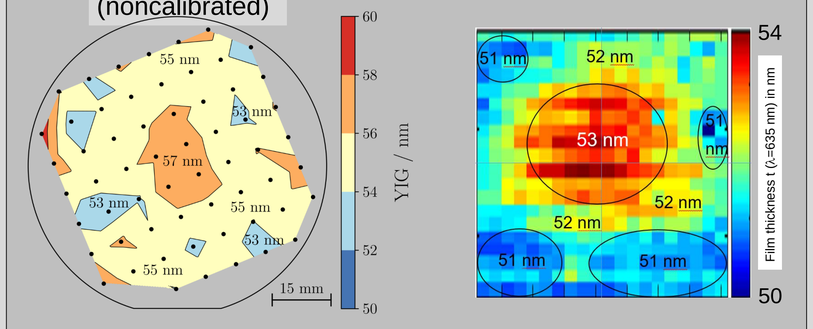
Topography / FMR properties of YIG films

Sample	Film thickness (nm)	S_q Surface roughnes (nm)	Defect quantity pits/scratches (70-200µm/≤5mm)	Damping α (plain/Pt-YIG) × 10^{-4}	Spin mixing conductivity (× 10^{18} m^{-2})
M37	48	0.4 ± 0.1	<10 / 3	-	-
M38	47	0.3 ± 0.1	<10 / 2	-	-
M39	49	0.3 ± 0.2	<10 / 2	-	-
M40	47	0.2 ± 0.1	<10 / 1	-	-
M41	50	0.3 ± 0.1	-	-	-
M19	69	-	-	3.3 / 6.5	2.3 ± 0.4
M20	68	-	-	3.6 / 6.1	2.0 ± 0.4
M21	63	-	-	3.6 / 6.3	1.8 ± 0.5
M22	62	-	-	3.4 / 6.7	2.1 ± 0.5
Average	-	**0.3 ± 0.1**	**<10 / 2**	**3.5 / 6.4**	**2.0 ± 0.2**

Film thickness homogeneity of 3-inch YIG films analyzed with different methods (reference: XRR)

X-ray fluorescence XRR Two-beam reflectance

t_1 = (55±2) nm (noncalibrated) t_1 = (53±1) nm t_1 = (52±1) nm

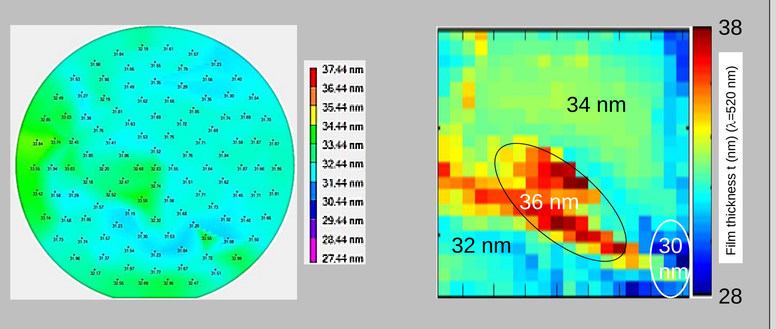


Map of the thickness distribution in a 3-inch area (60 spots, Ø~3 mm)

Map of the thickness distribution in a 40x50 mm^2 area (400 spots, Ø~2.5 mm)

Spectral reflectance XRR Two-beam reflectance

t_2 = (32±0.6) nm t_2 = (30±2) nm t_2 = (33±2) nm

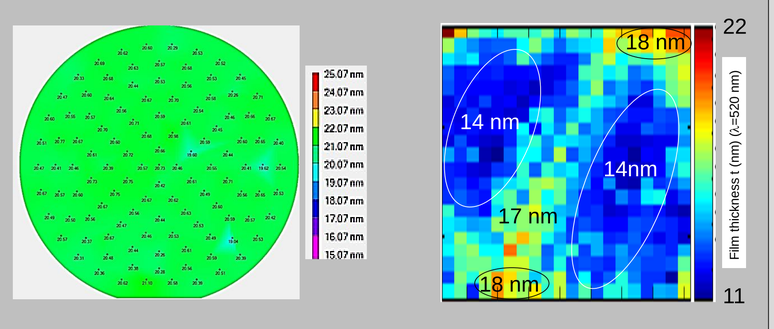


Map of the thickness distribution in a 3-inch area (115 spots, Ø~1.5mm)

Map of the thickness distribution in a 40x50 mm^2 area (400 spots, Ø~2.5 mm)

Spectral reflectance XRR Two-beam reflectance

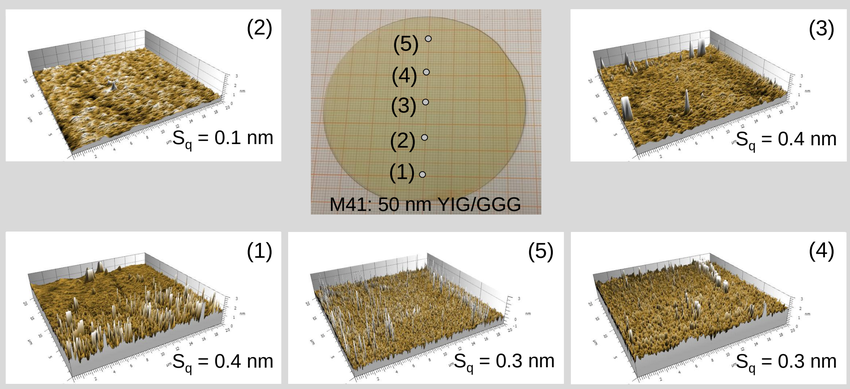
t_3 = (20±0.2) nm t_3 = (19±0.2) nm t_3 = (16±2) nm



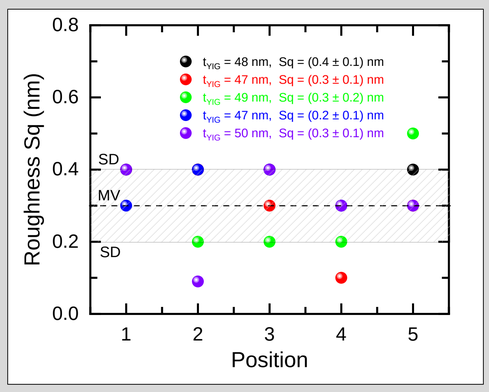
Map of the thickness distribution in a 3-inch area (115 spots, Ø~1.5 mm)

Map of the thickness distribution in a 40x50 mm^2 area (400 spots, Ø~2.5 mm)

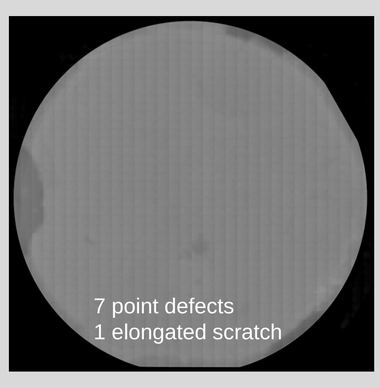
Surface roughness analysis and defectoscopy of 3-inch YIG films



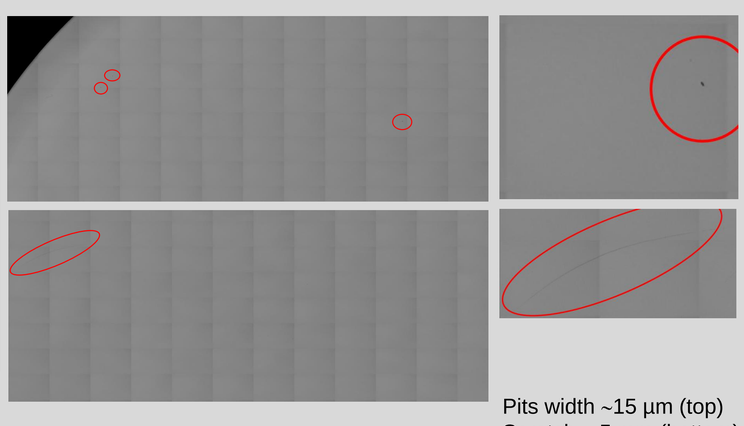
Surface roughness S_q along the Ø of 3-inch film M41 (AFM maps for 20 µm × 20 µm areas)



S_q for samples M37- M41grown under the same conditions



Optical defectoscopy of 3-inch film M37



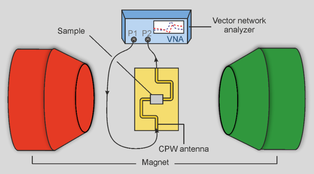
Pits width ~15 µm (top)
Scratch ~ 5 mm (bottom)

Spin mixing conductance

g_{eff} = 2 × 10^{18} m^{-2}

$$g_{\mathrm{eff}}^{\uparrow\downarrow} = \frac{4\pi M_s t}{\gamma h}\Delta\alpha$$

t : magnetic film thickness, g : Landé factor
γ : gyromagnetic ratio, h : Planck constant,
$\Delta\alpha$: change in Gilbert damping



Measurement parameters:
• Power -20 dBm
• 2 Averages

Frequency-dependent FMR data of plain YIG films & Pt/YIG bilayers (M21)

Conclusions

- The mapping of the film thickness shows homogeneous 3-inch YIG films with typical mean thickness variations of ± 2 nm over the wafer area investigated.
- AFM investigations show root mean square surface roughness S_q = (0.3 ± 0.1) nm.
- Light microscopic mapping shows less than 10 defects on ~75% of the surface area.
- The average spin mixing conductivity for as-grown 3-inch films is 2.0 ± 0.2 × 10^{18} m^{-2}.
- The degree of perfection, homogeneity and reproducibility of important film properties enables the realization of magnonic circuits based on 3-inch wafer technology.

References

[1] A. Chumak et al., Advances in magnetics: Roadmap on spin-wave computing, IEEE Transaction on Magnetics 58, 0800172 (2022)
[2] Q. Wang et al., Nanoscaled magnonic networks, Phys. Rev. App. 21, 040503 (2024)

Acknowledgement

Co-funded by the European Union

MANNGA project

We thank R. Meyer for the technical support.
Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the European Health and Digital Executive Agency (HADEA). Neither the European Union nor the granting authority can be held responsible for them.

Contact: INNOVENT e.V., Prüssingstr. 27 B, D-07745 Jena Phone +49 3641 2825-64 Fax. +493641 2825-30,
Dr. Carsten Dubs - Email: c.dubs@innovent-jena.de – Web site: http://www.innovent-jena.de
This poster was presented at the MAGNONICS 2025 conference, July 28th to August 1st 2025, in Cala Millor, Mallorca, Spain.