Radiation Resistant Magnetic Field Sensing Solution

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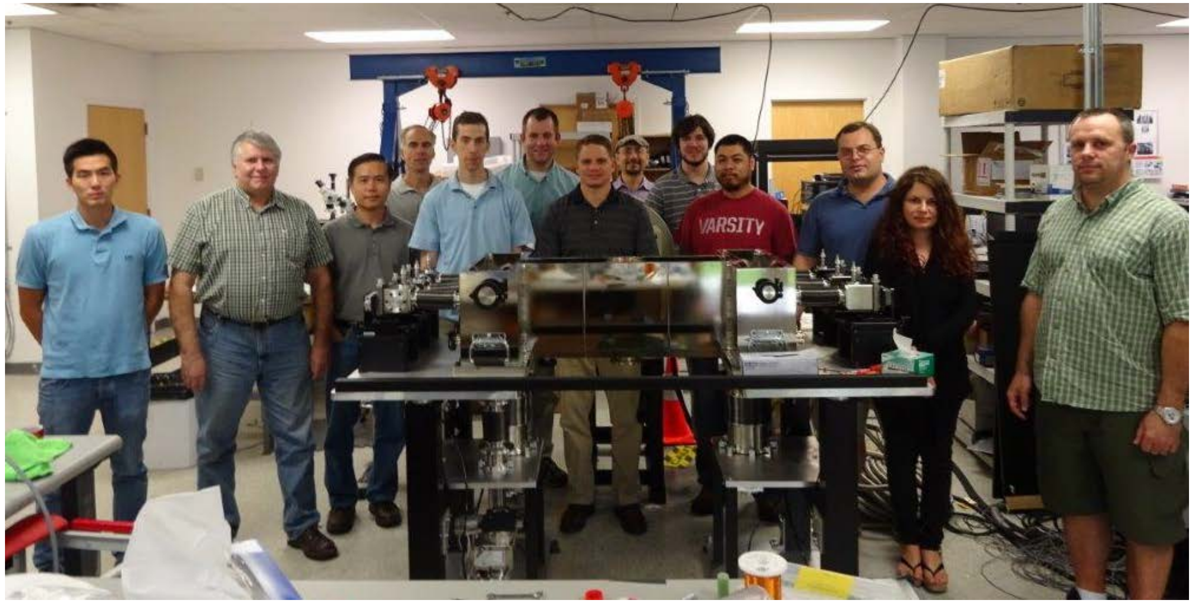
Dr. Brian Geist
Senior Scientist
Dr. Vladimir Kochergin
CEO/President
MicroXact Inc.

Agenda:

- Company information
- Addressed problem
- MicroXact's solution
- Phase II objectives
- Accomplishments to date
- Plans
- Questions

Background of MicroXact Inc.



- MicroXact was found in 2004.
- Organically grown (no outside investors)
- Strong technical staff
- Located at Virginia Tech Corporate Research Center, Blacksburg, VA, USA
- International network of sale reps/ distributors in all key markets (S. Korea, EU, Russia, Japan, China, India, Philippines, Malaysia, Australia, Saudi Arabia, Taiwan), office in Singapore
- Mostly serving academia/R&D. Few systems are installed/ used in production of highly specialized components.

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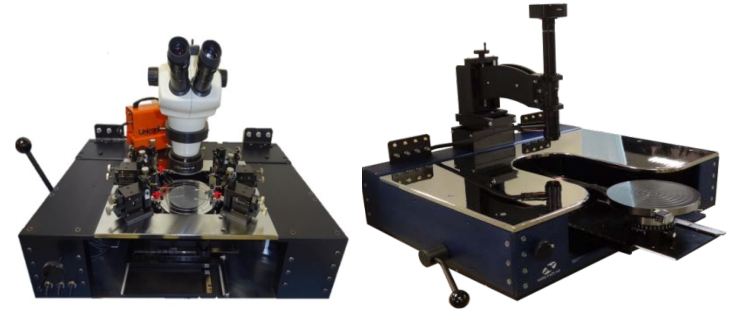
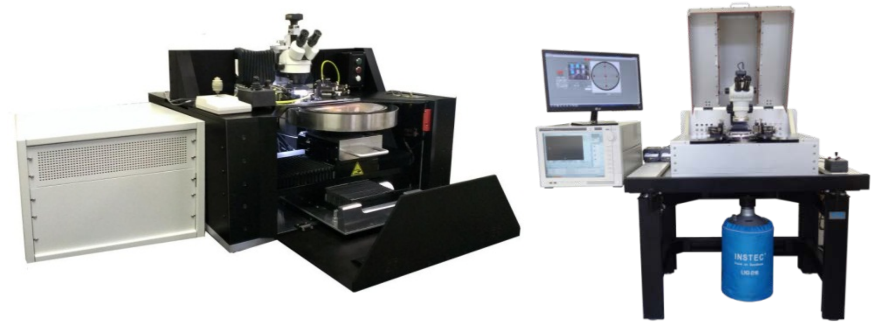
Products at a glance

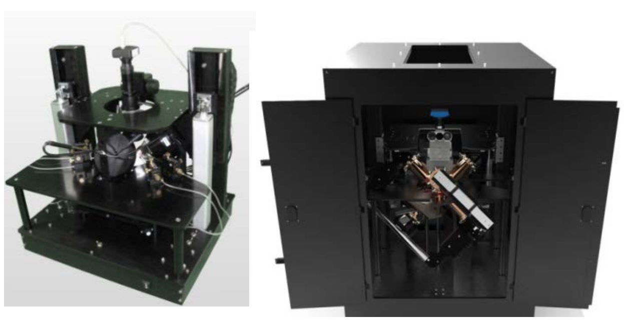
Manual probers for 100mm, 150mm and 200mm wafers. Cost-competitive and customizable to end-user needs



Semi-automated probers for 100mm, 150mm, 200mm and 300mm wafers. Very cost-competitive and customizable to end-user needs

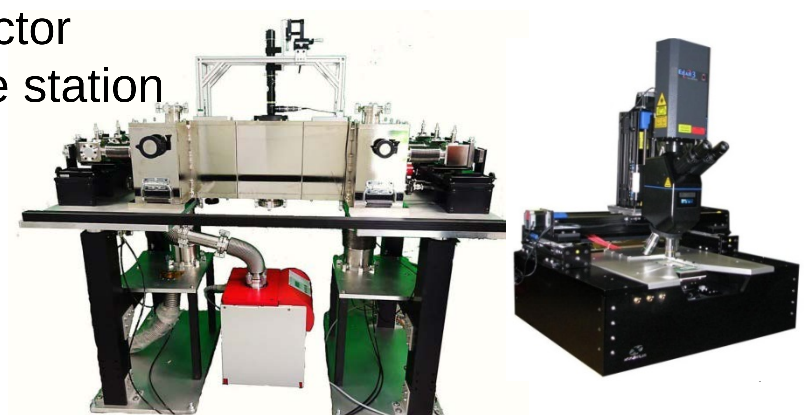
Fully-automated probers for 100mm, 150mm, 200mm and 300mm wafers. The most cost-competitive solution on the market.





Magnetic probe station. The first 3D vector magnetic probe station on the market.

Specialty probers: laser cutting probers, cryogenic probers



Addressed Problem

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- Highly localized (due to field gradients) magnetic field measurements (from 0.2T to 5T with $dB/B<10^{-4}$) are needed in the high radiation (Mrads/year) environments of the rare isotope beam facility at MSU and pretty much any other accelerator facility in the US and worldwide.
- Typical electronic sensors (even hardened) survive only a few weeks in such environments, and replacement of the sensor (downtime of ~$10k/day, not counting the cost of instrumentation) is costly.
- Fiber optics temperature and strain sensors, on the other hand, were proven to be radiation hard, however to date, fiber optic sensors meeting technical specifications listed above were not demonstrated, not to mention studied for radiation hardness.
- This project is targeting development

MicroXact Solution

- Fiber optic sensing solution, intrinsically radiation harder than any electronic solution and far cheaper, more reliable and easier to install than a potential atomic magnetometry solution.

- The survivability of temperature and strain fiber optic sensors in a radiation environment was demonstrated to 200GRad gamma (R. Fielder, et al., “High Neutron Fluence Survivability Testing of Advanced Fiber Bragg Grating Sensors,” STAIF 2004, NM, February 2004) and to 5.0 x 10^{19} n/cm^2 for fast neutrons. I.e., Mrad per year does not seem to be too much to ask.

- MicroXact proposed to develop a sensor based on TGG crystals and a proprietary interrogation instrument to fulfil the project goals

Fiber optic magnetic field sensing, our solution

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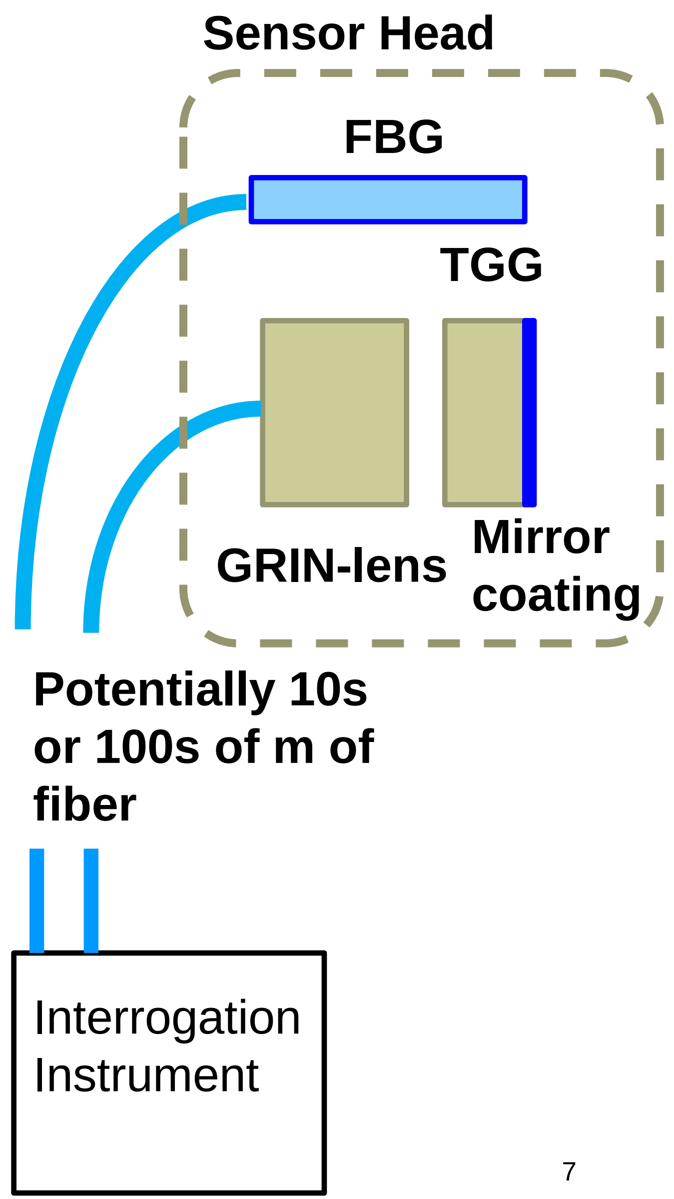
- Terbium Gallium Garnet (TGG) is paramagnetic with a high Verdet constant (for 632nm wavelength it shows 134 rad $T^{-1}m^{-1}$) that can be used for highly sensitive, highly localized (possibly down to mm^3)fiber optic magnetic field sensing of large magnetic fields.
- However, its Verdet constant is highly temperature dependent, calling for a fiber Bragg grating (FBG) sensor to be co-located with it.
- It is not known how much of an effect the radiation will have on TGG's Verdet constant, but if it is noticeable, it can be eliminated as follows
  - By employing a reference TGG sensor or 2nd reference FBG sensor.
  - By employing two wavelengths approach for TGG interrogation, since if the effect will be present, it is expected to be wavelength-dependent.



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Our solution, advantages

- The sensor head should be small (FBG+TGG sensors will be less than 5mm in diameter together)
- Will work at high fields (5T no problem)
- $dB/B<10^{-4}$ is no problem (similar interrogation solution utilizing YIG assembled by Vladimir Kochergin had 6 orders of dynamic range)
- The solution will be radiation hard and if a significant effect of radiation on the Verdet constant will be identified (it is not expected), several approaches are available to mitigate these effects, to extend the functionality of the sensor head to years compared to just weeks with electronic sensors.
- The solution is expected to be relatively inexpensive: interrogation instrument $25k, replicable sensor head (probably below $2k) and will represent significant savings over lifetime.

Comparison to other magnetic field sensors

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Technology	Advantage	Limitations
Hall sensors	Well-developed technology, standard for measurement of large magnetic fields, accurate	Poor radiation hardness
Thin film Faraday or Kerr effect-based sensors	Small size, radiation-immune leads (fiber), adequate accuracy	Low saturation field ⇔Not suitable for large magnetic fields
Fiber spool-based sensors	Well-developed technology, standard for measurement of currents (large magnetic fields)	Large size, not suitable for measurements of spatially variable magnetic fields
Magnetostriction-based sensors	Small size, radiation-immune leads (fiber), adequate accuracy	Low saturation field ⇔Not suitable for large magnetic fields
MicroXact's Technology	Radiation immune, suitable for measurements of large magnetic fields, accurate, small size	

Phase II project objectives

- **Objective 1: Evaluate in-situ effects of neutron and gamma radiation on TGG refractive index and Verdet constant.**

Status: The objective is complete.

- **Objective 2: Develop a stand-alone sensor and interrogation system and verify its performance over a wide range of magnetic fields and temperatures.**

Status: The objective is 90% complete.

- **Objective 3: Verification of system performance.**

Status: In progress.

- **Objective 4: Develop mature commercialization strategy.**

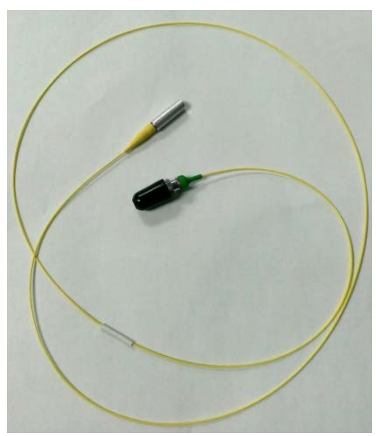
Status: The objective is 70% complete.

Conclusions: MicroXact is on track to complete all objectives by the end of the project

System status

- Proprietary sensor design and construction (completed, sensor performance verified in house)
- Proprietary, patent-pending sensor interrogation instrumentation to enable significantly better dynamic range and sensitivity. System development is in its final stage
- Advanced software enabling straightforward integration with auxiliary instrumentation.

Sensor prototype



Stand-alone system prototype for interrogation of up to 3 sensors

Study of radiation effects on TGG absorption

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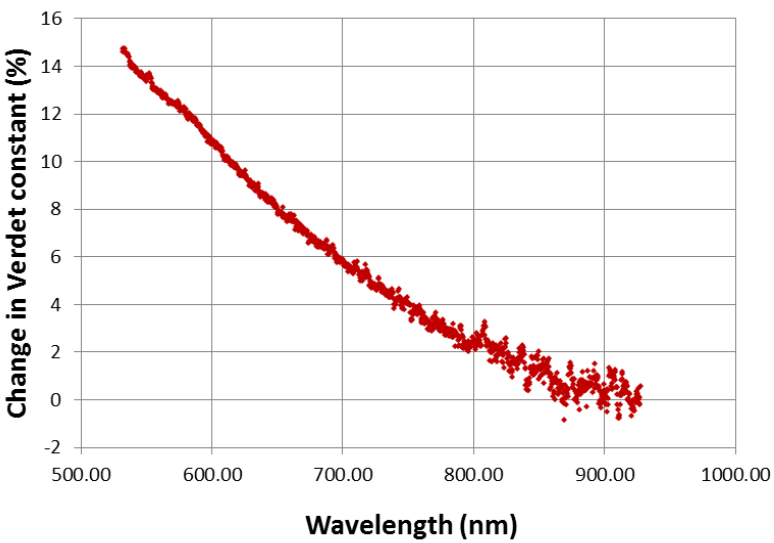
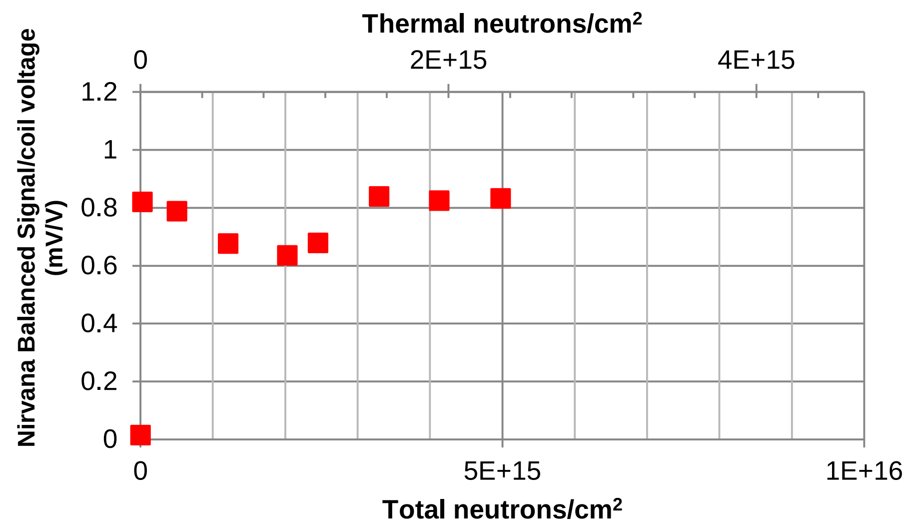
Verdet Constant (in rad/(T•m)) of TGG crystals with a 2 cm length

	532 nm	632 nm
Non-irradiated	-233.76 ± 9.38	-211.85 ± 2.62
Non-irradiated B	-215.30 ± 10.60	-195.46 ± 4.27
Irradiated	-187.23 ± 5.52	-190.48 ± 3.82



Estimated percent change in the Verdet constant as a function of wavelength after exposure to radiation—At wavelengths above 800 nm, the degradation of the signal is in the background noise



Sensor response to an applied magnetic field as a function of thermal neutron and total neutron exposure

Future plans

- Completion of interrogator development
- Final testing of interrogator/sensor at ORNL.
- One more testing of the system at OSU NRL.
- Final testing of the system at MSU FRIB

Conclusions

- New sensor/interrogation instrument design will result in significant cost savings to DoE through eliminating the need for frequent probe replacement/recalibration.
- The project is on track to complete system development and verification at the FRIB facility by the end of Phase II.
- Initial contacts with a number of accelerator facilities in US confirmed strong interest of the community for the solution under development
- MicroXact, based on its previous successes in commercializing products development on SBIR/STTR funding builds confidence in great commercialization perspectives of the technology under development

Questions?