When the FET project is over – what next?

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Plasmon Enhanced Terahertz Electron Paramagnetic Resonance (PETER)

Horizon 2020 - FET

- Partners: BUT, USTUTT, NANOGUNE, Thomas Keating
- Period: 1/2018 – 12/2020
- Grant: 2,898,683.75 EUR
- Funding scheme: RIA
- Proposal Nr: 767227
- Activity: FETOPEN-RIA-2017-1

Horizon 2020 - FET

Proposal Evaluation Form

	EUROPEAN COMMISSION Horizon 2020 - Research and Innovation Framework Programme	**Evaluation Summary Report - Research and innovation actions**

Call: H2020-FETOPEN-1-2016-2017
Funding scheme: RIA
Proposal number: 767227
Proposal acronym: PETER
Duration (months): 36
Proposal title: Plasmon Enhanced Terahertz Electron Paramagnetic Resonance
Activity: FETOPEN-RIA-2017-1

N.	Proposer name	Country	Total Cost	%	Grant Requested	%
1	VYSOKE UCENI TECHNICKE V BRNE	CZ	687,646.25	23.72%	687,646.25	23.72%
2	UNIVERSITAET STUTTGART	DE	809,980	27.94%	809,980	27.94%
3	Asociacion - Centro de Investigacion Cooperativa en Nanociencias - CIC NANOGUNE	ES	613,352.5	21.16%	613,352.5	21.16%
4	Thomask Keating Ltd	UK	787,705	27.17%	787,705	27.17%
	Total:		2,898,683.75		2,898,683.75	

Evaluation Summary Report

Evaluation Result

Total score: 5.00 (Threshold: 0)

H2020 FET OPEN project PETER

PETER

Božena Čechalová – project manager

Joris van Slageren

Tomáš Šikola

BRNO UNIVERSITY OF TECHNOLOGY

University of Stuttgart
Germany

TK INSTRUMENTS

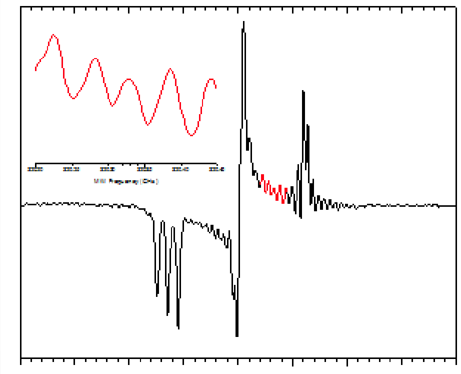
CIC nanoGUNE
nanoscience cooperative research center

Rainer Hillenbrand

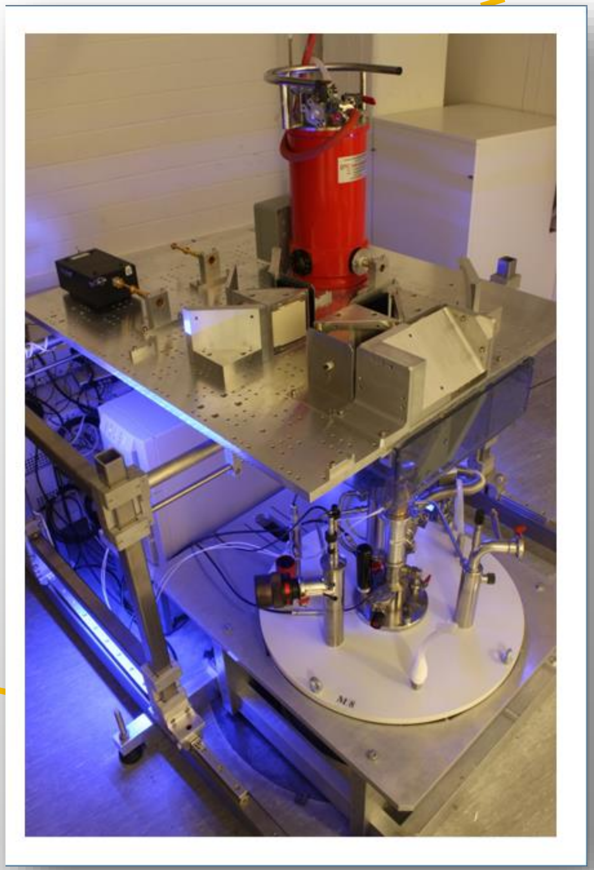
Richard Wylde

Electron Paramagnetic Resonance

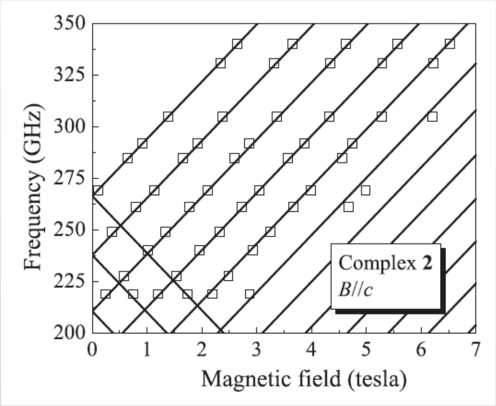
- Based on similar principles as very well known nuclear magnetic resonance
- Used in many scientific disciplines such as medicine, chemistry, physics, etc



HF signal



Zeeman splitting



Plasmon Enhanced THz Electron Paramagnetic Resonance

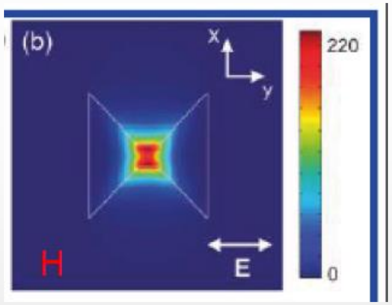
Overview

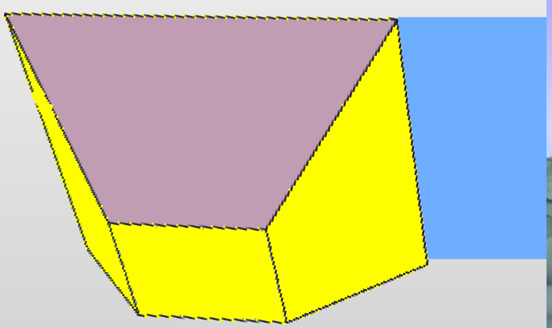
General aim:

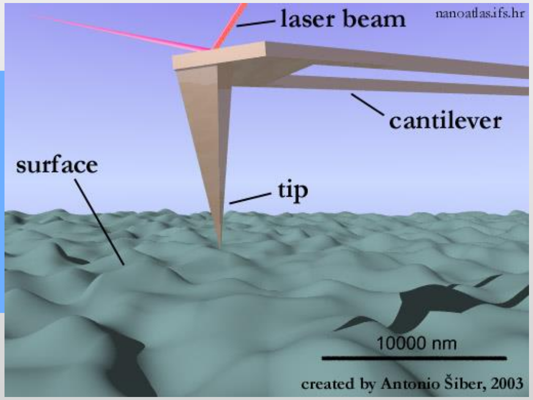
- Combine advantages of high-frequency electron paramagnetic resonance with scanning probe microscopy. Achieve a working prototype.

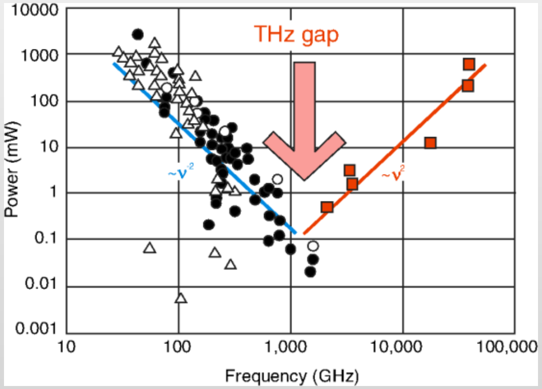
Novelty

- First magnetic field enhancement with plasmonic antennas (localization beyond diffraction limit)
- First scanning probe HFEPR (spatial resolution < 1 μm) .
- Closing of the THz gap (higher sensitivity)







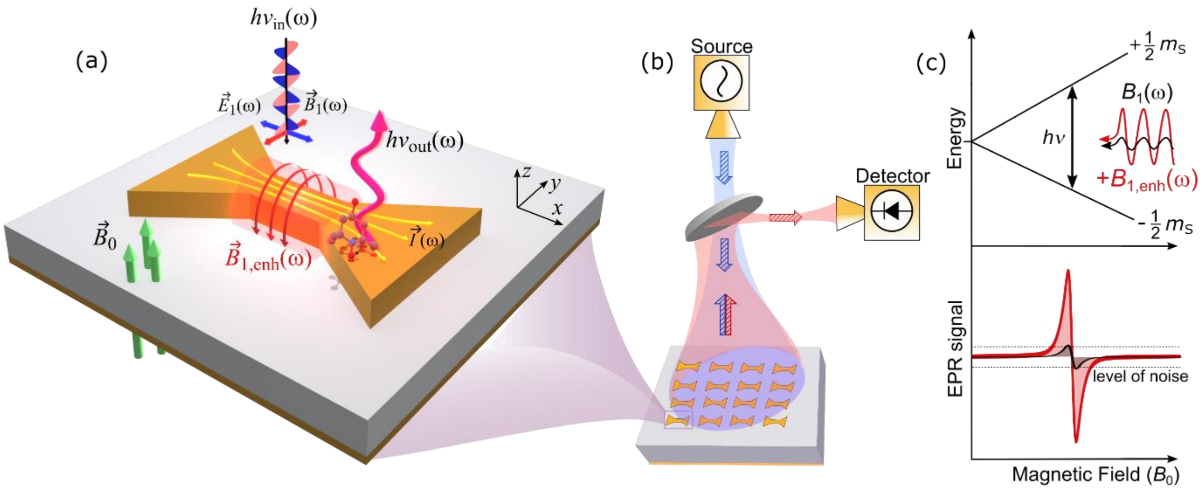


Opt. Eng. 52(3), 033203 (Mar 15, 2013). doi:10.1117/1.OE.52.3.033203

Plasmon enhanced (PE) THz EPR Spectroscopy

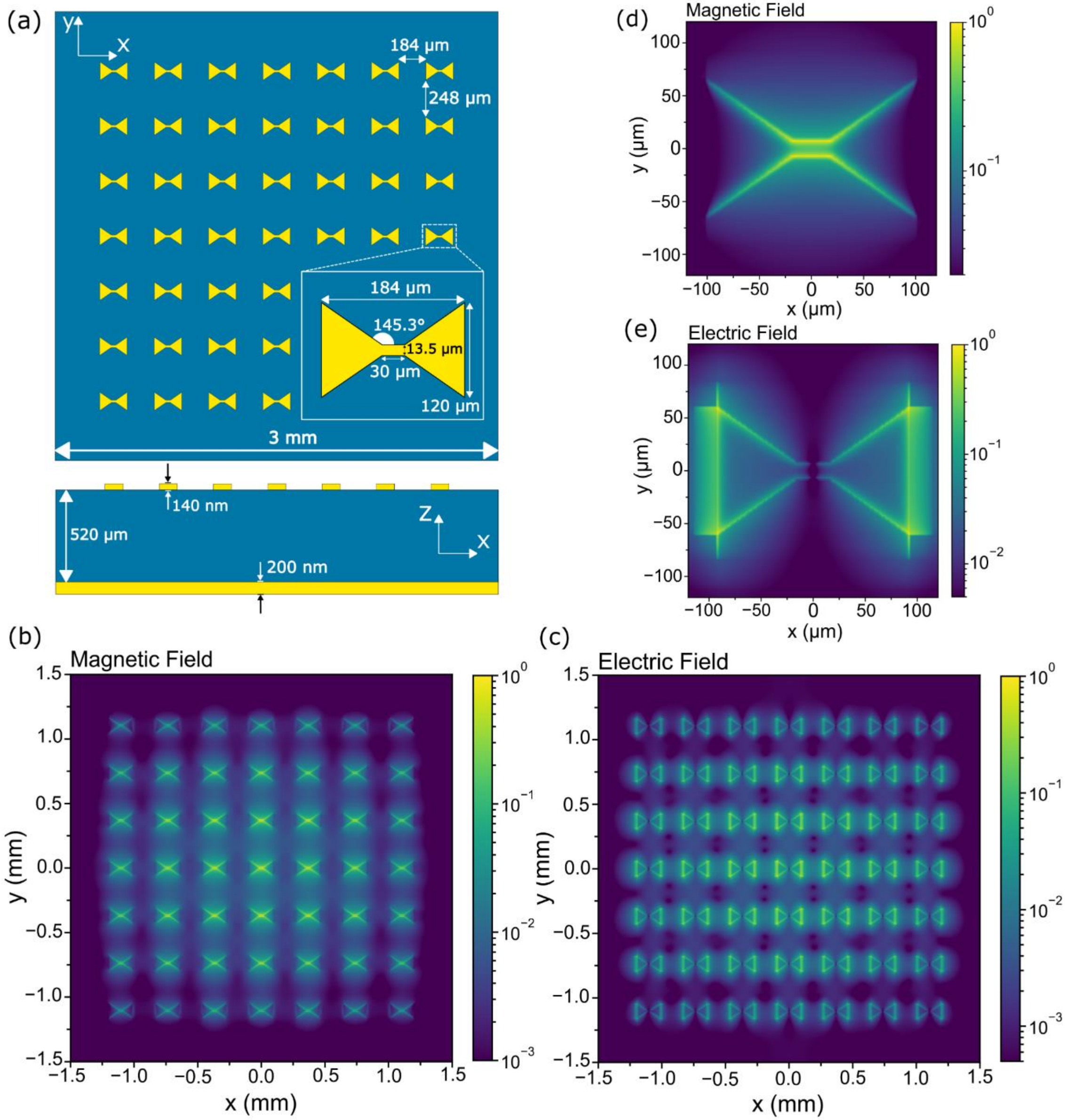
Plasmonic metasurfaces

Plasmonic metasurfaces are versatile structures able to manipulate electromagnetic fields beyond natural possibilities. Their application can be extended to magnetic resonance techniques working at terahertz frequencies. This provides a series of significant and unprecedent advantages in terms of sensitivity and integrability when dealing with nanosized materials as well as ultra-thin molecular films.

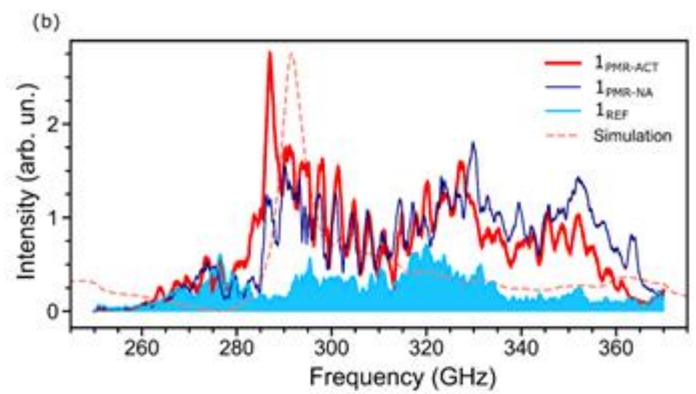


Array of diabolo antennas - plasmonic metasurface

Optimal designed structures, FDTD simulations of magnetic and electric field enhancements

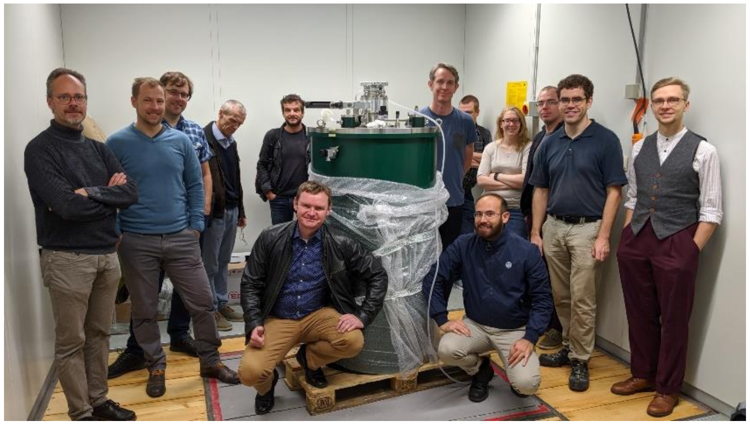


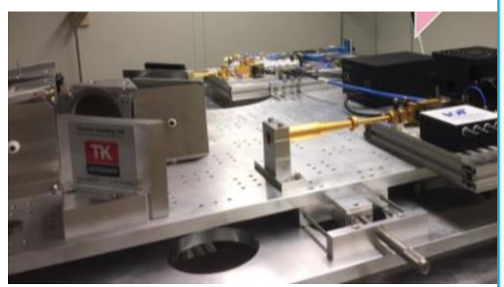
Lorenzo Tesi,
Plasmonic Metasurface Resonators to Enhance Terahertz Magnetic Fields for High Frequency Electron Paramagnetic Resonance,
Small Methods, 2021, 5, 2100376

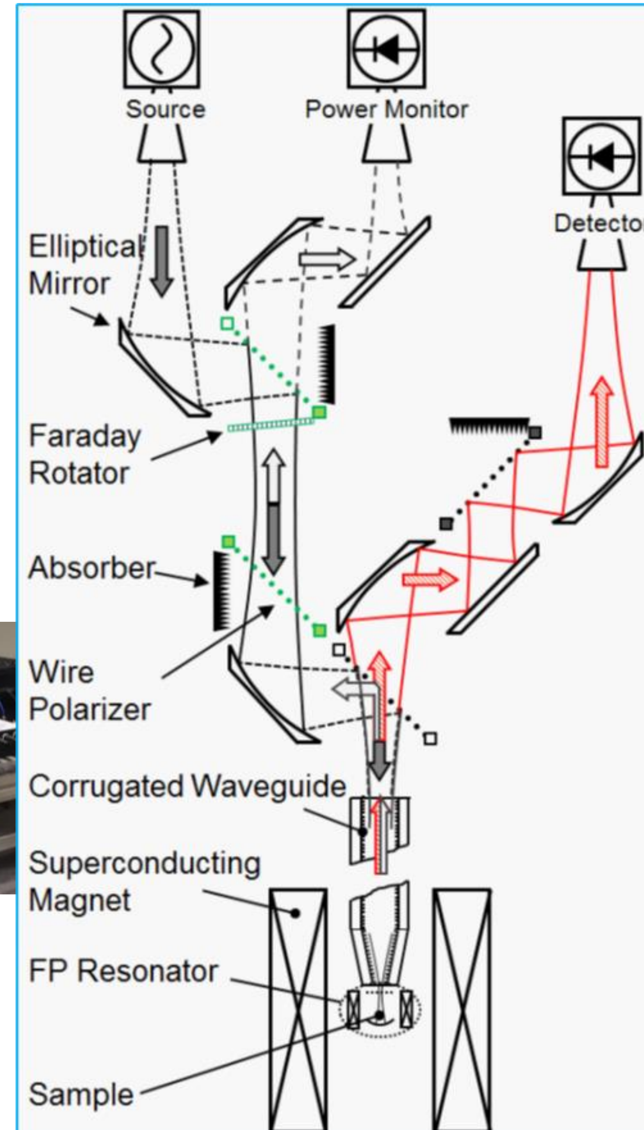


Assembly and optimization of the platform for PE THz EPR microscopy

Arrival of the cryomagnet to Stuttgart

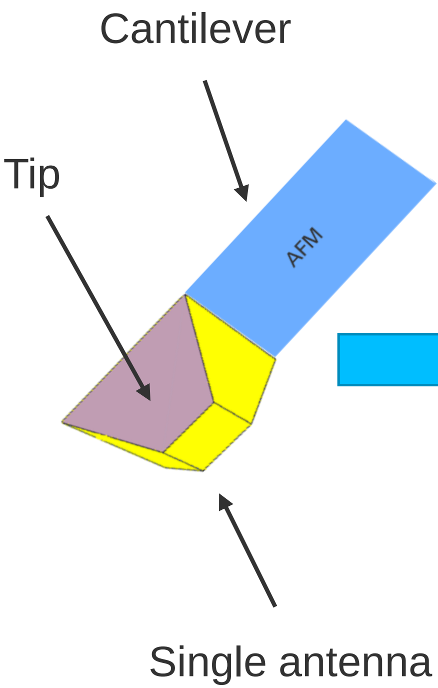


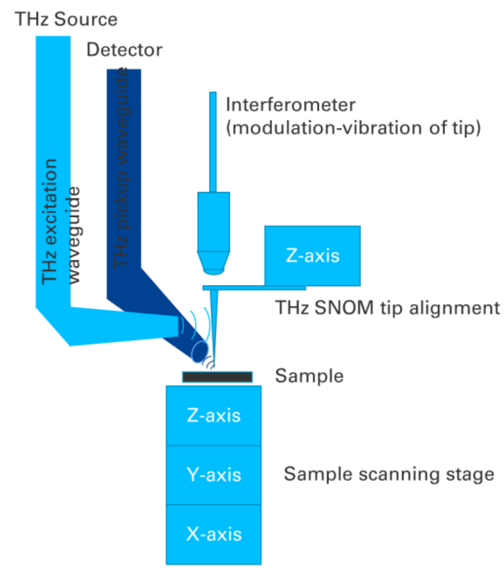


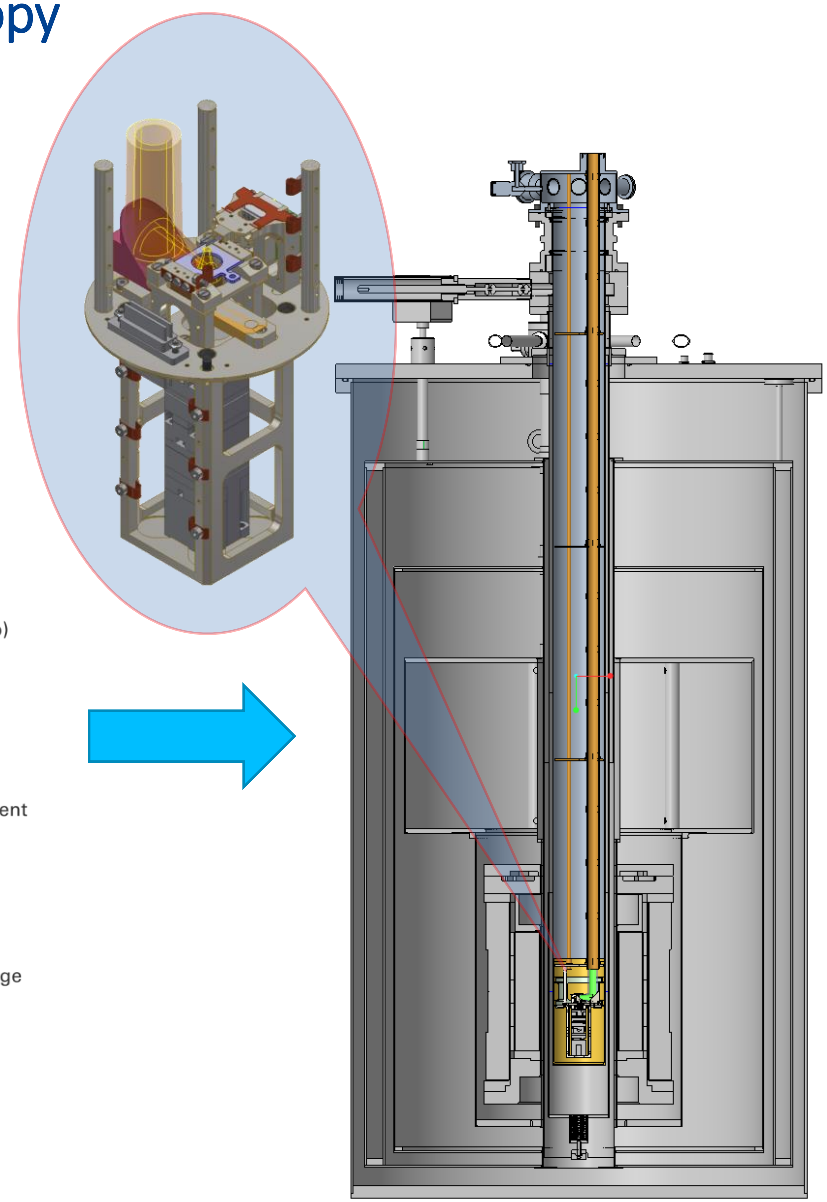


Plasmon Enhanced (PE) THz EPR Microscopy

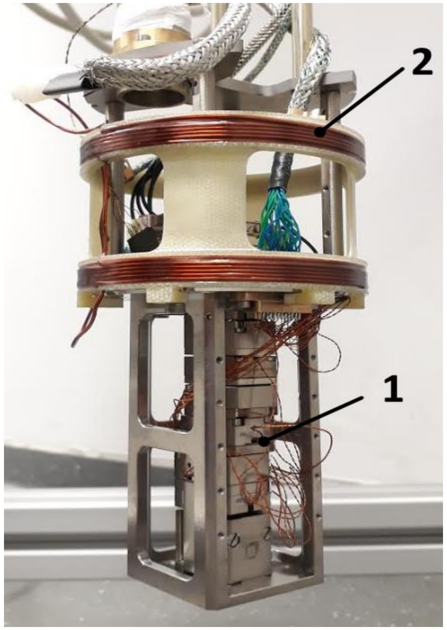
From an antennas array
back to a single antenna

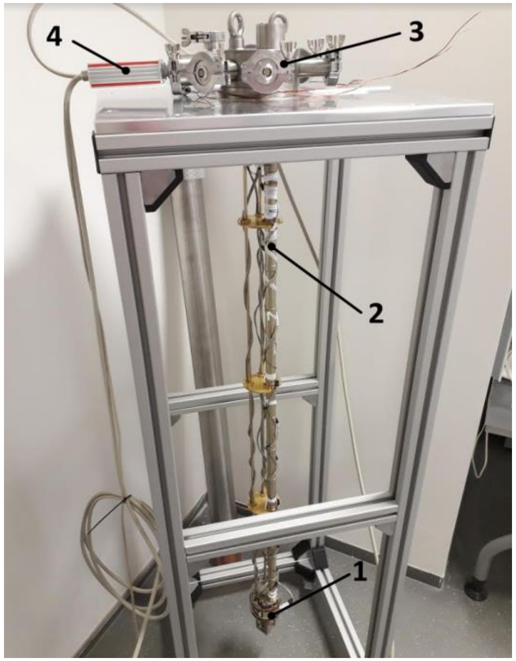




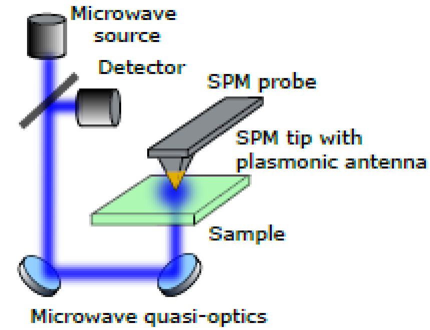


Final assembling and testing of the SPM unit

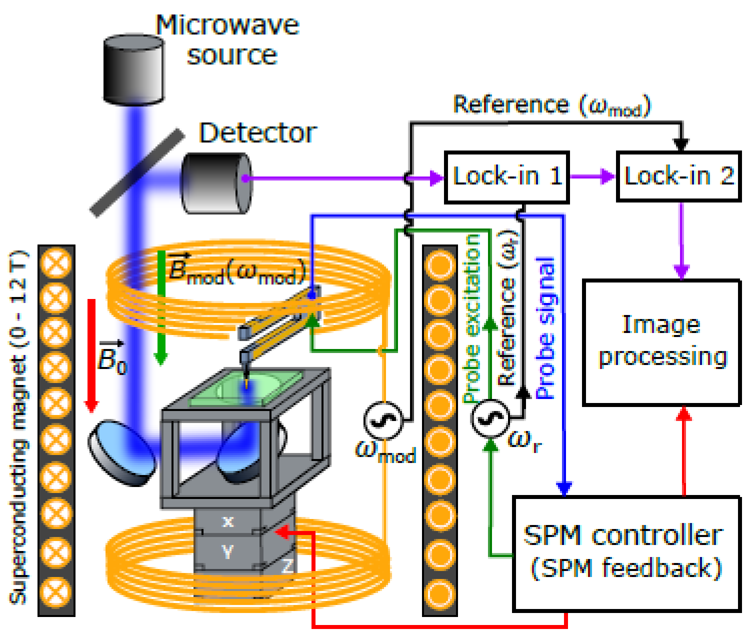




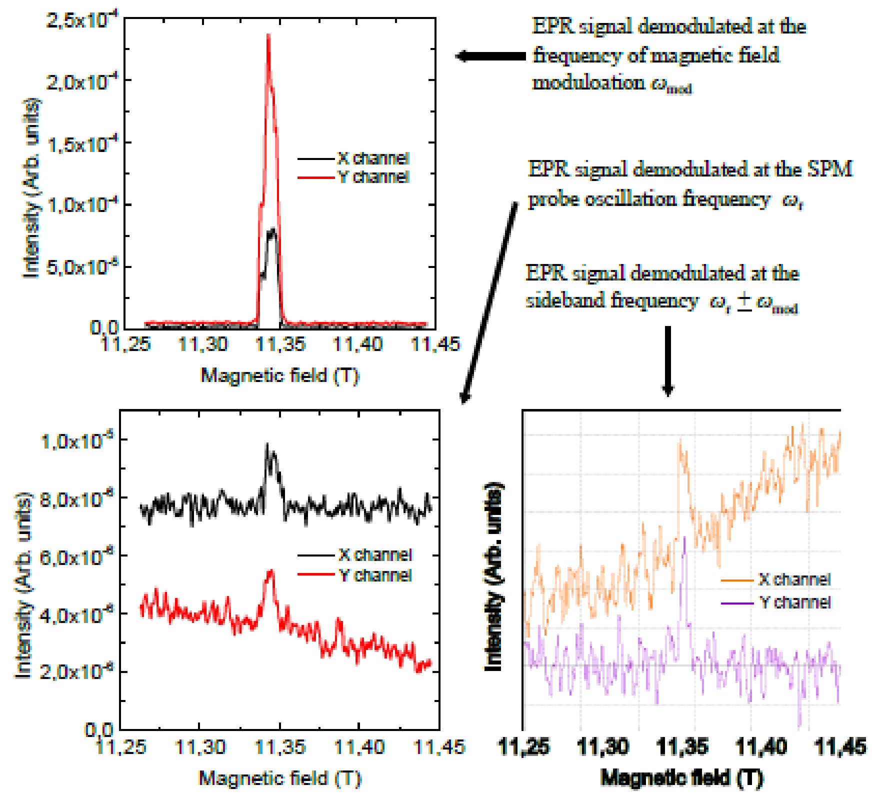
Application of the platform for PE THz EPR microscopy



SPM/EPR detection scheme



NV center diamond



Outcomes

1. **PE THz Spectroscopy**

   - Proof of concept

     (30-fold signal increase – opening ways to thin film/nanoscale samples)

2. **PE THZ Microscopy**

   - Designed SPM/EPR unit was prooven to be capable to operate at LT down to 5 K and high magnetic field up to 12 T
   - SPM/EPR detection scheme was successful in extracting the EPR signal from the SPM probe (not proven the response from the tip yet)

General problem

Horizon 2020 - FET

FET: Interdisciplinary, Novelty, S&T targeted, Foundational, High-Risk, Long-term vision

- **Long-term vision**: a new, original or radical long-term vision of technology-enabled possibilities going far beyond the state of the art
- **Breakthrough S&T target**: scientifically ambitious and technologically concrete breakthroughs, plausibly attainable within the life-time of the project.
- **Foundational**: the breakthroughs must have the potential to become the basis for a new line of technology not currently available.
- **Novelty**: new ideas and concepts, rather than the application or incremental refinement of well established ones.
- **High-risk**: the potential of a new technological direction depends on a whole range of factors that cannot be apprehended from a single disciplinary viewpoint.
- **Interdisciplinary**: the proposed collaborations must go beyond current mainstream collaboration configurations in joint S&T research, and must aim to advance different scientific and technological disciplines together and in synergy towards a breakthrough.

Too short time to bring the new ideas and concepts to a commercial level

Our post-FET activities

1. Continuation in work on Proof of Concept of PE THz EPR microscopy
   - ➢ Financing from other resources
   - ➢ Difficult to keep an intense colaboration:
     - the developed setup available at Stuttgart only
     - interdisciplinary character: the project partners should work together on experiments

2. Looking for proper project schemes
   - ➢ FET-OPEN (CSA-LSP action) – submitted proposal

Our post-FET activities

FETOPEN-03-2018-2019-2020
Type of action: CSA-LSP
(Coordination and support action Lump sum)

Proposal title: Towards Plasmon-enhan[illegible] Terahertz Electron
Paramagnetic Reson[illegible]lysis
Acronym: TETERA
Coordinator: THOMAS KEAT[illegible]ED

Failed

Objectives:

1. **Market research [illegible]ment:** To determine the marketability of an off-the-shelf PETER sy[illegible] increase the potential applications for PETER, and expose this technique and spectrometer to a wider community basis.
2. **Preparation for market analysis and market release:** standard protocols, a user manual, and informational documents.
3. **IPR protection:** patents

Requested EU contribution: 99 956 EUR

Our post-FET activities

1. Continuation in work on Proof of concept of PE THz EPR microscopy
   - Financing from other resorces
   - Difficult to keep intense colaboration:
     - the developed setup available at Stuttgart only
     - interdisciplinary character: close collaboration between the project partners still needed

2. Looking for proper project schemes
   - ~~FET-OPEN (CSA-LSP action) - submitted~~
   - EIC projects
     - EIC Pathfinder: advanced research on breakthrough / game-changing technologies
     - EIC Transition: transforming research results into innovation opportunities
     - EIC Accelerator: for individual companies to develop and scale up breakthrough innovations with high risk and high impact

Conclusions - recommendations

1. Do not let discourage yourself by the highly challenging programme criteria
2. Find an original, rather risky idea, discuss and analyse it with your partners in detail a sufficient time in advance (better in a few stages – time demanding process, half a year at least?)
3. The idea might be more easily found out of the “main stream” – for inspiration consult the list of successful projects from the previous calls
4. The idea should have a significant impact and outreach (not only within scientific community, but also on innovations, industry, society)
5. Kind of proof of concept (at least simulations)
6. Consortium should be properly composed (not all partners must be top players, including the coordinator) – complementary expertise and skills (company). Do not be afraid of taking the role of the coordinator (higher chance to get partners in). Less partners, the better for “steering” the team (average number: 5-6 partners)
7. Do not underestimate “soft” activities - dissemination
8. Take the same attention to all 3 project Sections (Excellence, Impact, Implementation) - loss of any point is „fatal“

Thank you!

Plasmon Enhanced (PE) THz Electron Paramagnetic Resonance

General aim

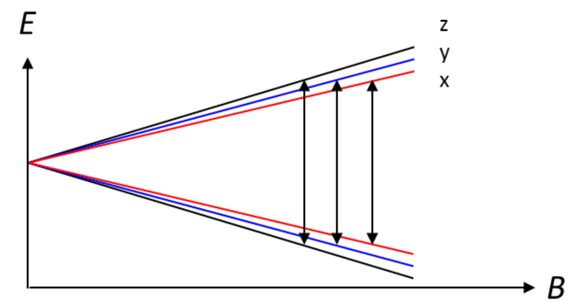
- Combine advantages of high-frequency electron paramagnetic resonance with scanning probe microscopy. Achieve a working prototype.

Novelty

- First magnetic field enhancement with plasmonic antennas (localization beyond diffraction limit)
- First scanning probe HFEPR (spatial resolution < 1 μm) .
- Closing of the THz gap (higher sensitivity)

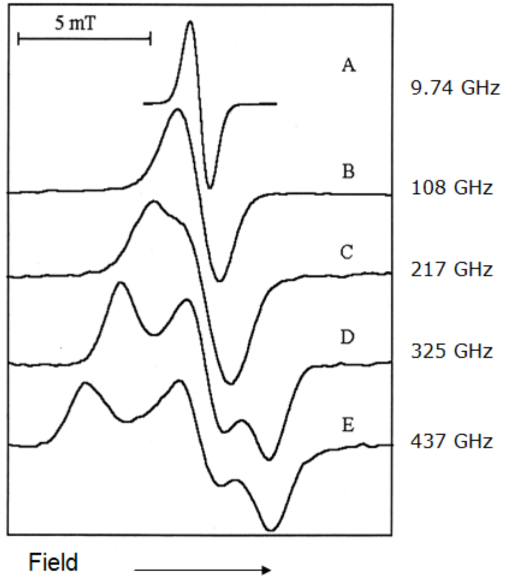
Why magnetic field enhancement at THz frequencies?

Plasmon Enhanced THz Electron Paramagnetic Resonance



Magnetic field enhancement

- Electron paramagnetic resonances are magnetic dipole transitions.
- Magnetic dipole transitions are much weaker than electric dipole transitions.
- Magnetic field can be enhanced by plasmonic resonant structures – arrays of antennas (metasurfaces)

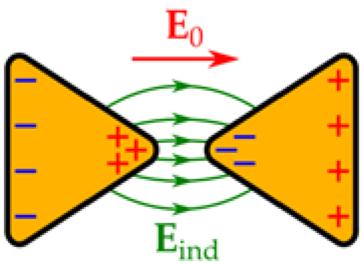


THz Electron Paramagnetic Resonance

- EPR interrogates paramagnetic centers in biology, chemistry, materials science and physics.
- Reasons for going to higher frequencies in EPR:
  - Easy access to large energy splittings
  - Improve g-value resolution

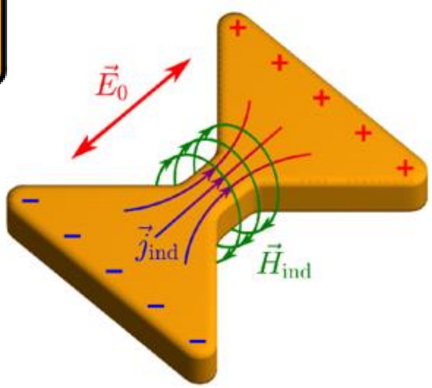
$$\hat{\mathcal{H}} = D\hat{S}_z^2 + E\left(\hat{S}_x^2 - \hat{S}_y^2\right) + \mu_B \mathbf{B} \cdot \underline{\underline{g}} \cdot \hat{\mathbf{S}}$$

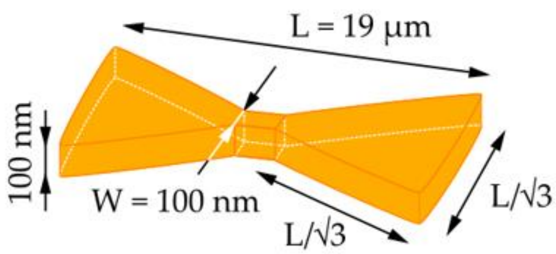
Individual plasmonic antenna for magnetic field enhancement (upon resonance)

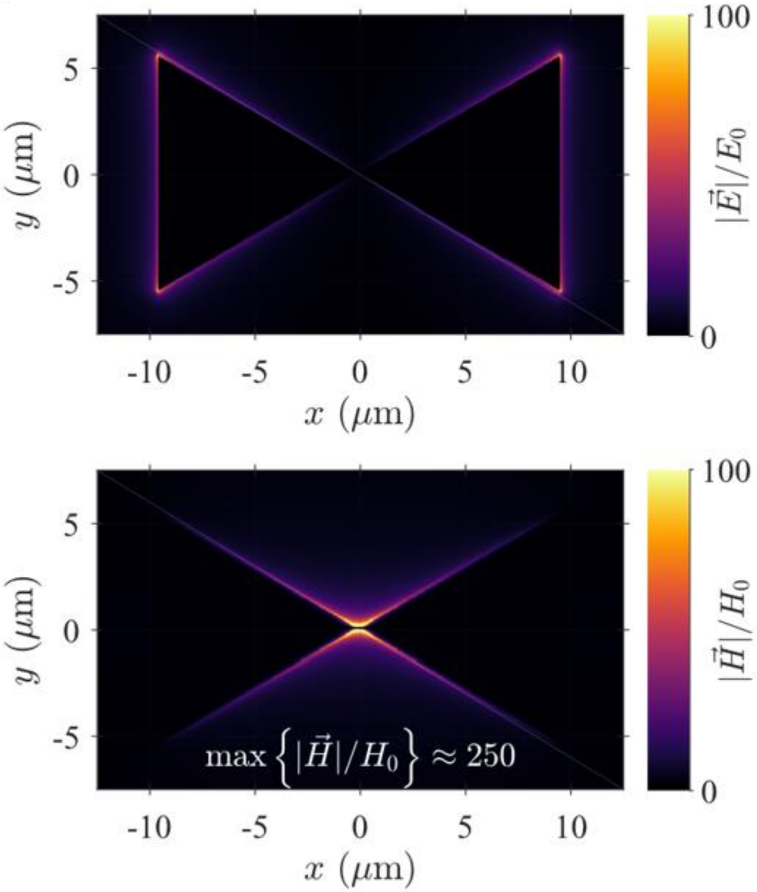


Bow-tie antenna

Diabolo gold antenna

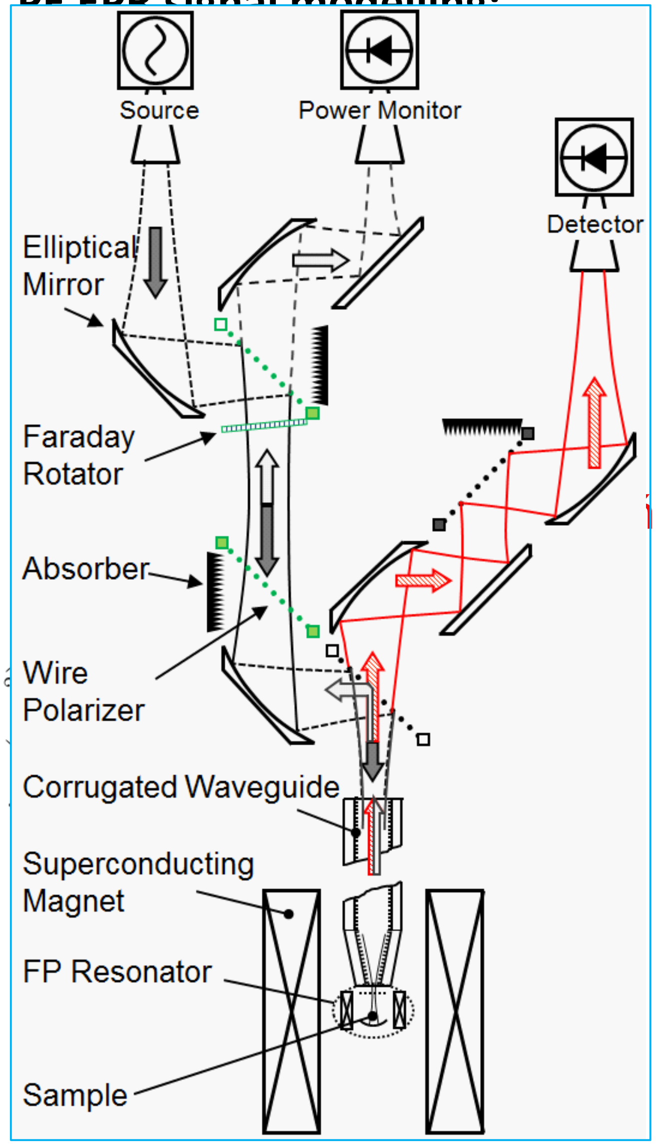




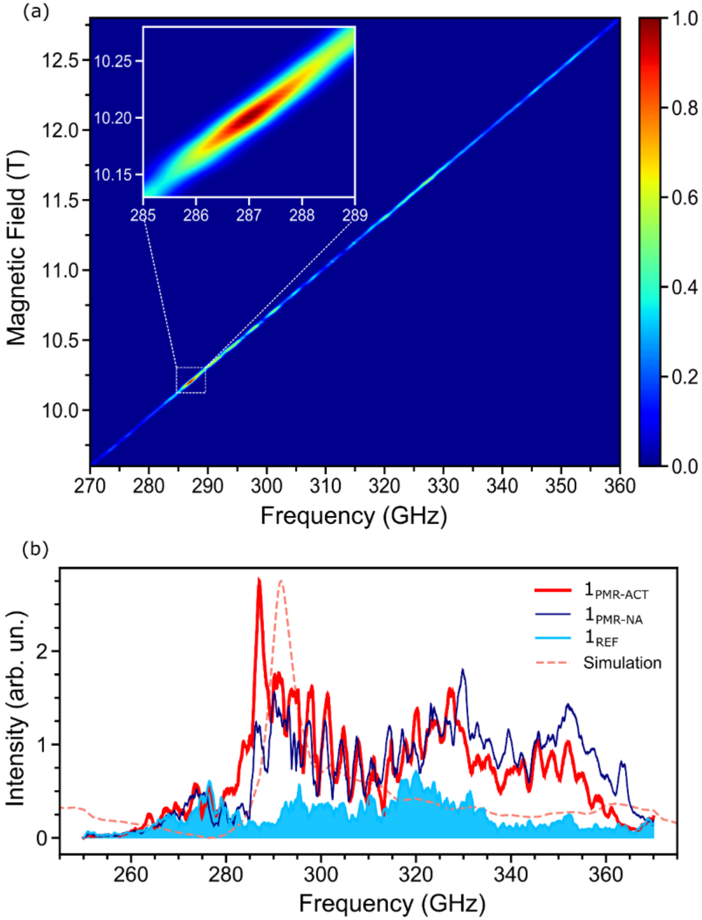


Plasmon Enhanced (PE) THz EPR Spectroscopy

PE EPR signal modelling:

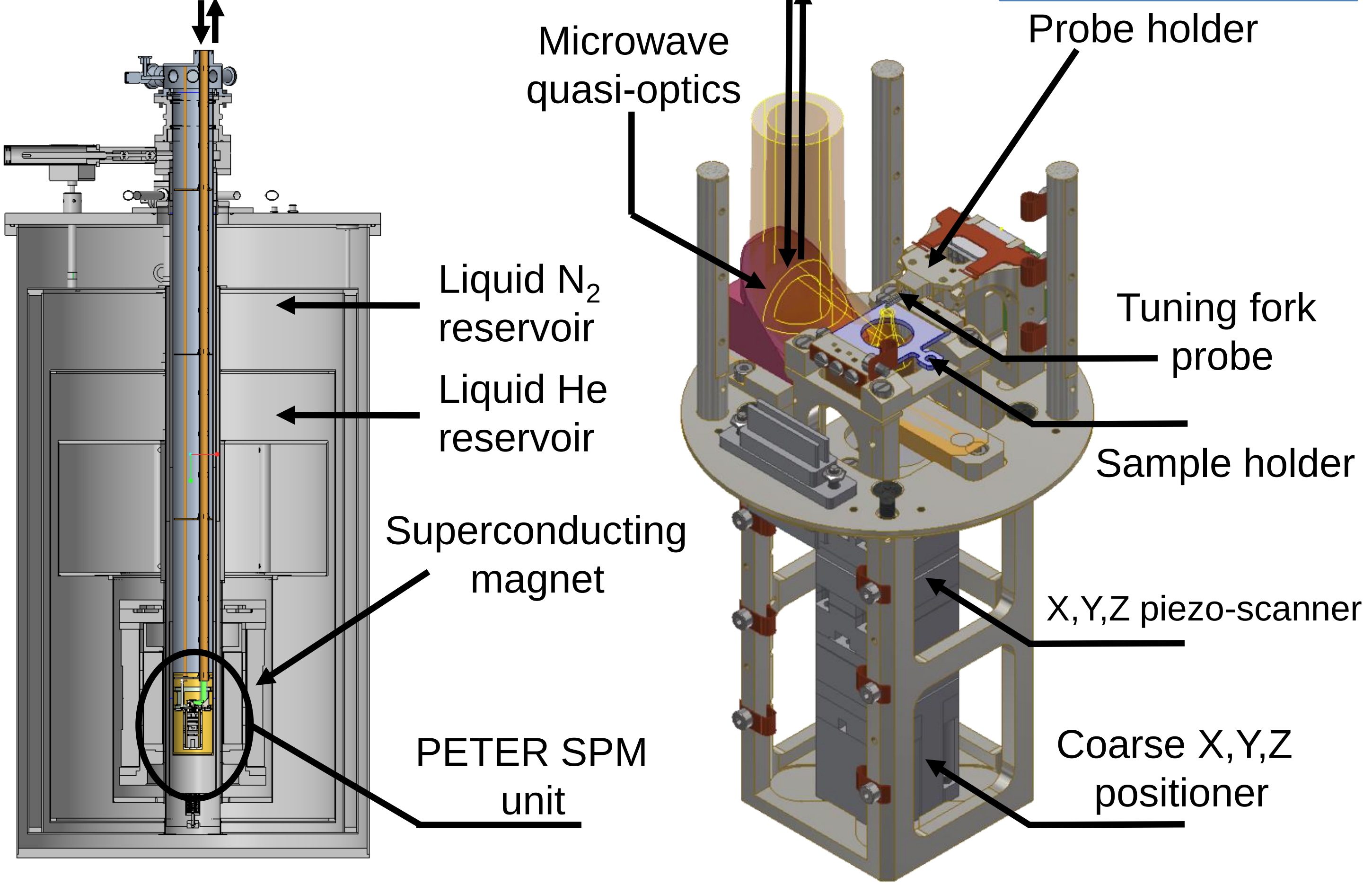


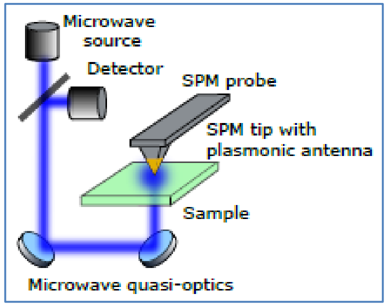
PE EPR spectroscopy experiment (antennas covered by TEMPOL, 10 K)



Lorenzo Tesi: Plasmonic Metasurface Resonators to Enhance Terahertz Magnetic Fields for High Frequency Electron Paramagnetic Resonance
Small Methods, 2021, 5, 2100376

Design of an SPM unit





Plasmon Enhanced THz Electron Paramagnetic Resonance

Partners

- Rainer Hillenbrand, CIC nanoGUNE, Tolosa Hiribidea, 76, E-20018, Donostia - San Sebastian, Spain, r.hillenbrand@nanogune.eu
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- Richard Wylde, Kevin Pike, Thomas Keating Ltd, Station Mills, Billingshurst, West Sussex, RH14 9SH, UK, R.Wylde@terahertz.co.uk, K.Pike@terahertz.co.uk
- Tomáš Šikola, Vlastimil Křápek, Jan Čechal, CEITEC and Institute of Physical Engineering, Brno University Technology, Purkyňova 123, 612 00 Brno, Czech Republic, sikola@fme.vutbr.cz, Vlastimil.Krapek@ceitec.vutbr.cz, Cechal@fme.vutbr.cz,

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Kevin Pike

Tomáš Šikola

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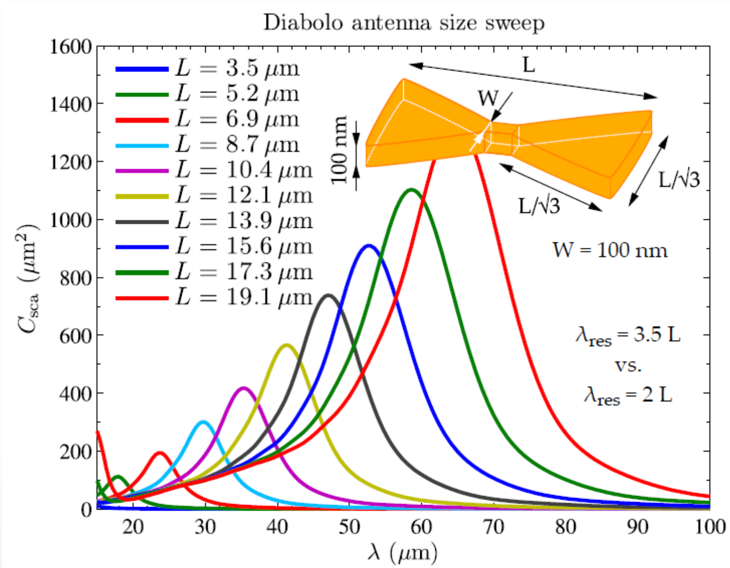
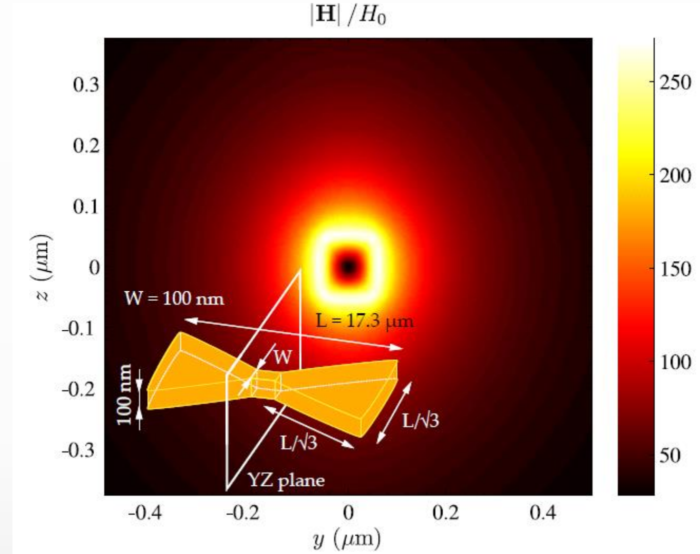
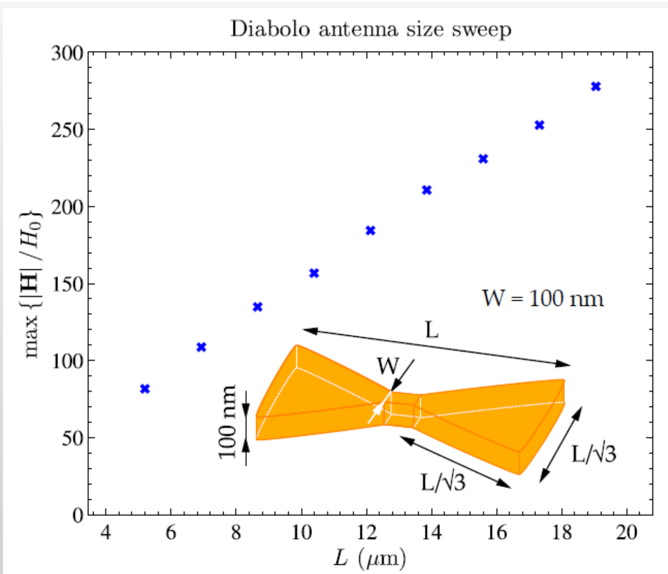
Plasmon Enhanced Electron Paramagnetic Resonance

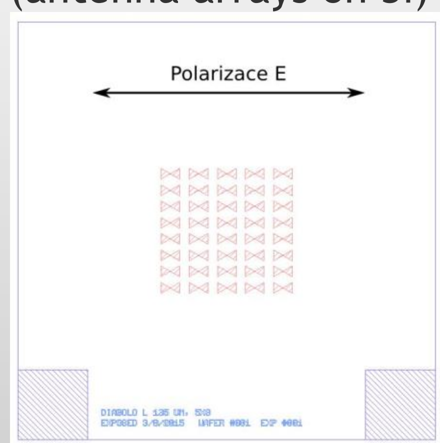
PE THz EPR spectroscopy







Sample for spectroscopy
(antenna arrays on Si)



Plasmon Enhanced Electron Paramagnetic Resonance

PE THz EPR spectroscopy

Design and Fabrication of Plasmonic Structures.

Lead NanoGune

- Preliminary work by CEITEC/BUT.
- Types: diabolo, split-ring, swiss roll.
- Au and/or graphene. Discussion point
- Testing at USTUTT