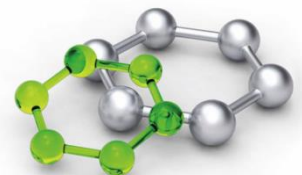


# Plasmon Enhanced Terahertz Electron Paramagnetic Resonance (PETER)



T. Šikola

*Institute of Physical Engineering, Brno University of Technology,  
Central European Institute of Technology (CEITEC-BUT)*



# 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	VYSOKÉ UCENÍ TECHNICKÉ V BRNĚ	CZ	687,646.25	23.72%	687,646.25	23.72%
2	UNIVERSITÄT STUTTGART	DE	809,980	27.94%	809,980	27.94%
3	Asociación - Centro de Investigación 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)**

# 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.

# Plasmon Enhanced THz Electron Paramagnetic Resonance

## Partners

- Rainer Hillenbrand, CIC nanoGUNE, Tolosa Hiribidea, 76, E-20018, Donostia - San Sebastian, Spain, [r.hillenbrand@nanogune.eu](mailto:r.hillenbrand@nanogune.eu)
- Joris van Slageren, Petr Neugebauer, Institute of Physical Chemistry, University of Stuttgart, Pfaffenwaldring 55, 70569 Stuttgart, Germany, [slageren@ipc.uni-stuttgart.de](mailto:slageren@ipc.uni-stuttgart.de), [petr.neugebauer@ipc.uni-stuttgart.de](mailto:petr.neugebauer@ipc.uni-stuttgart.de)
- Richard Wylde, Kevin Pike, Thomas Keating Ltd, Station Mills, Billingshurst, West Sussex, RH14 9SH, UK, [R.Wylde@terahertz.co.uk](mailto:R.Wylde@terahertz.co.uk), [K.Pike@terahertz.co.uk](mailto:K.Pike@terahertz.co.uk)
- Tomáš Šíkola, Vlastimil Křápek, Jan Čechal, CEITEC and Institute of Physical Engineering, Brno University Technology, Purkyňova 123, 612 00 Brno, Czech Republic, [sikola@fme.vutbr.cz](mailto:sikola@fme.vutbr.cz), [Vlastimil.Krapek@ceitec.vutbr.cz](mailto:Vlastimil.Krapek@ceitec.vutbr.cz), [Cechal@fme.vutbr.cz](mailto:Cechal@fme.vutbr.cz)



Božena Čechalová  
manager

– project

Ceitec BUT, [Bozena.Cechalova@ceitec.vutbr.cz](mailto:Bozena.Cechalova@ceitec.vutbr.cz)



Jan  
Čechal



Rainer  
Hillenbrand



Joris  
van Slageren



Petr  
Neugebauer



Richard  
Wylde



Kevin  
Pike



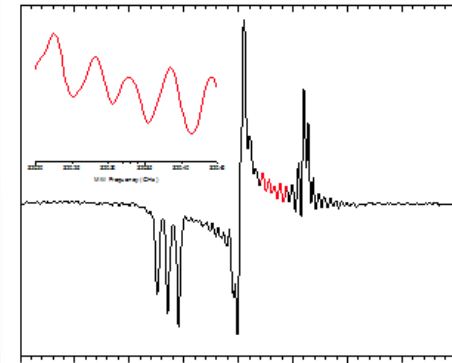
Tomáš  
Šíkola



Vlastimil  
Křápek

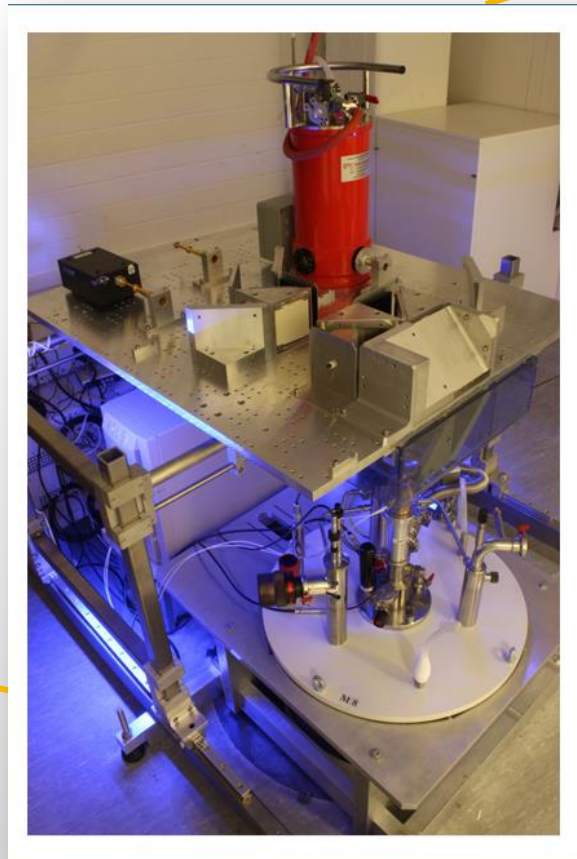
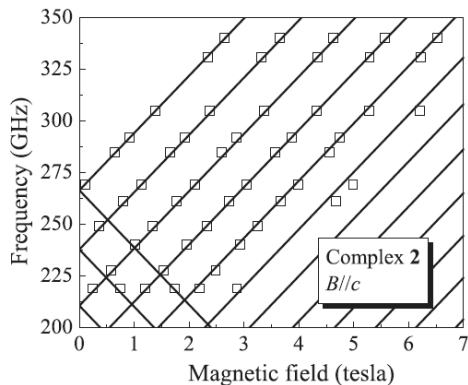
# Electron Paramagnetic Resonance

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

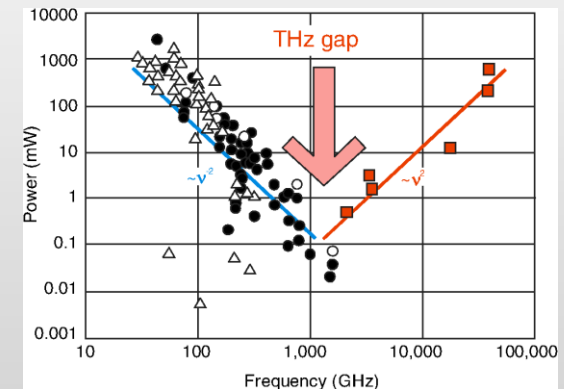
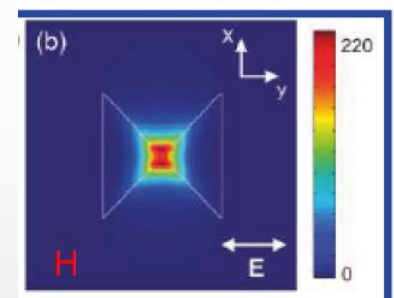
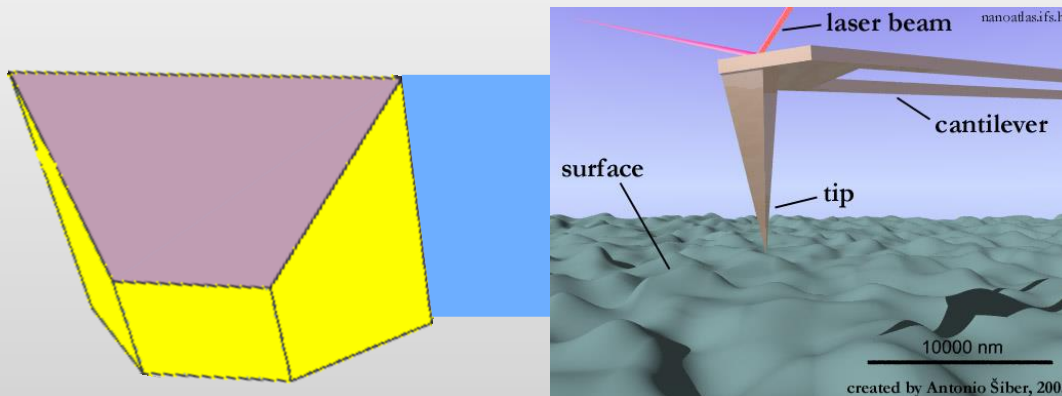
## Overview

General aim:

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

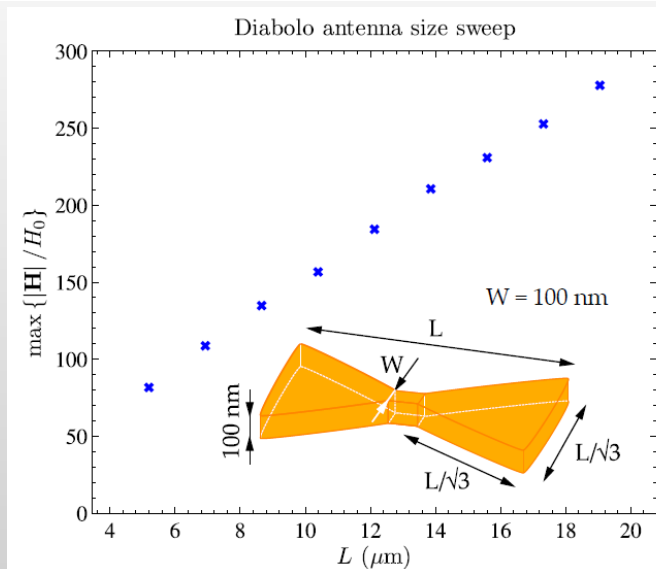
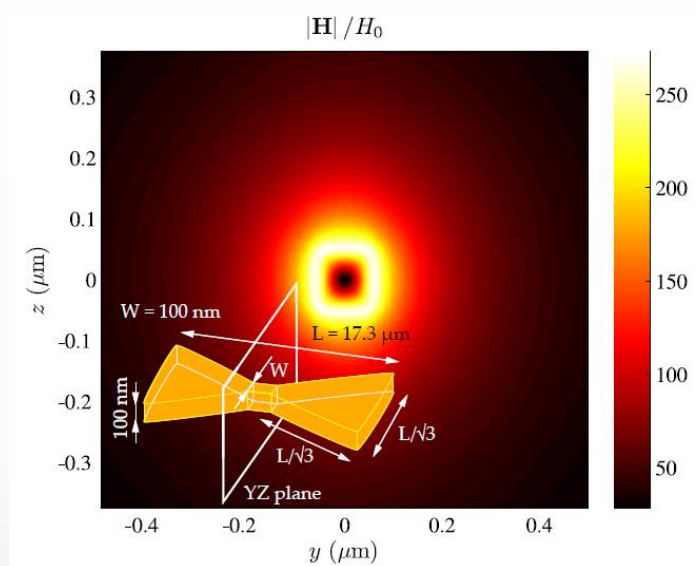
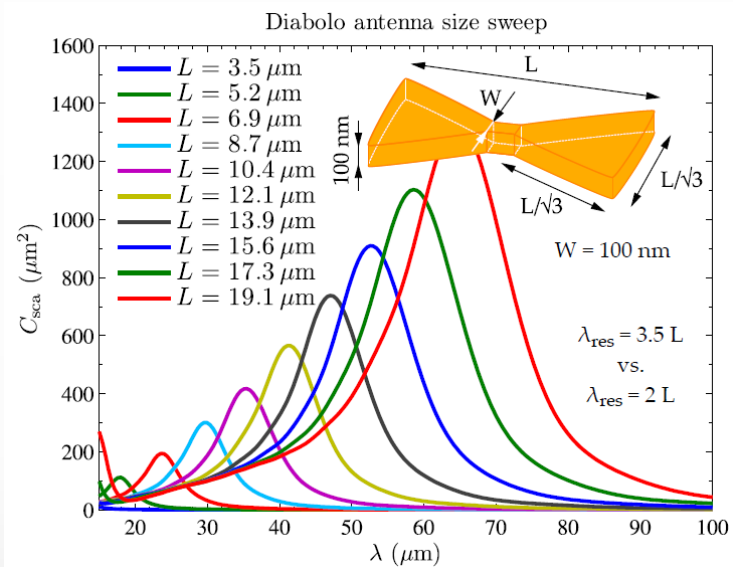
Novelty

- First magnetic field enhancement with plasmonic antennas (localization beyond diffraction limit)
- First scanning probe HFEPR (spatial resolution  $< 1 \mu\text{m}$ ) .
- Closing of the THz gap (higher sensitivity)

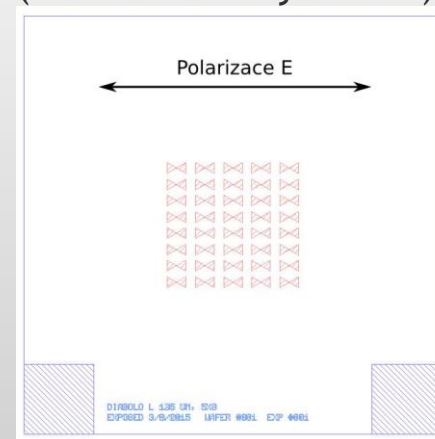


# Plasmon Enhanced Electron Paramagnetic Resonance

## PE THz EPR spectroscopy



Sample for spectroscopy  
(antenna arrays on Si)

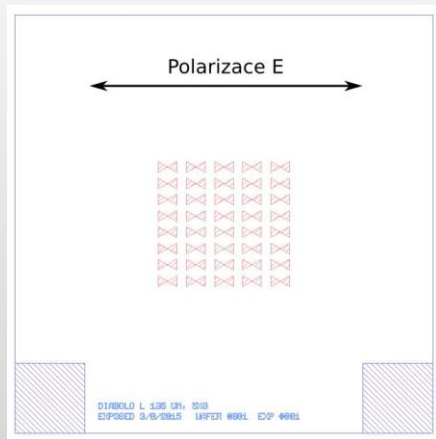


# Plasmon Enhanced Electron Paramagnetic Resonance

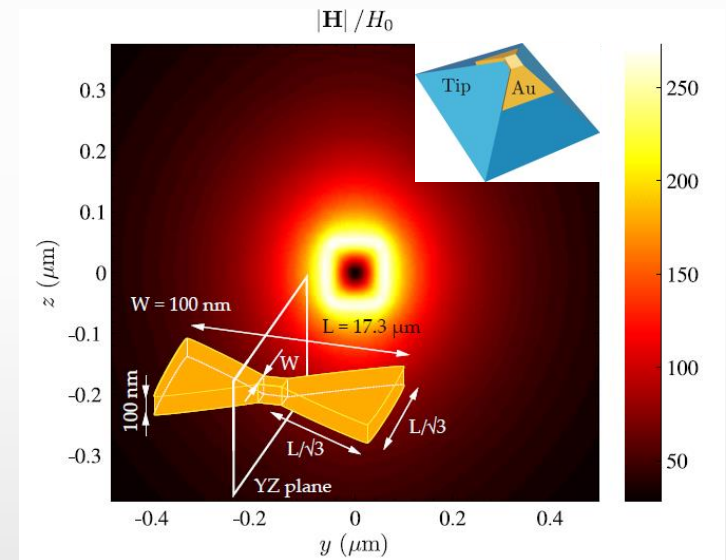
## PE THz EPR spectroscopy

### Design and Fabrication of Plasmonic Structures.

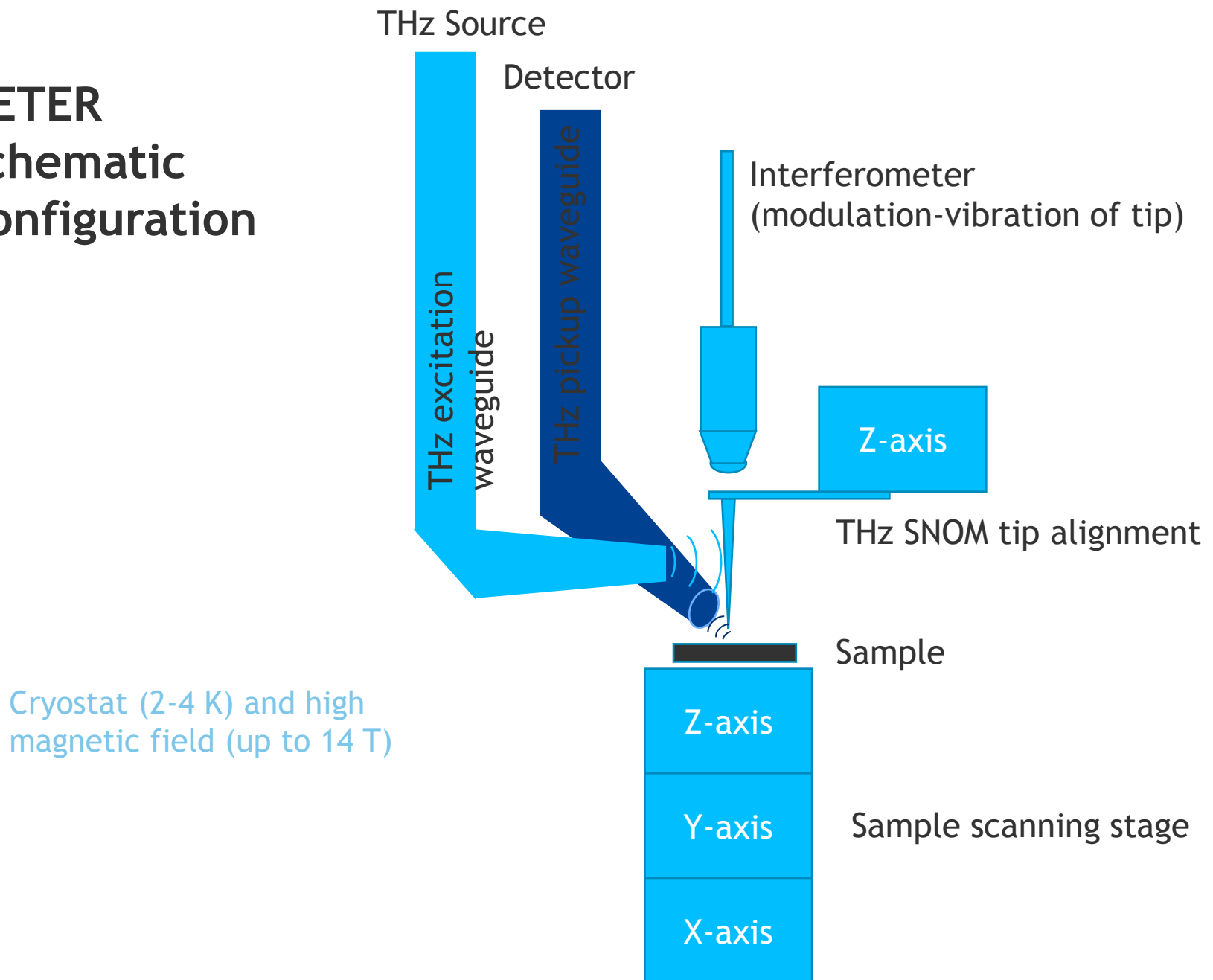
- Preliminary work by CEITEC/BUT.
- Types: diabolo, split-ring, swiss roll.
- Au and/or graphene. **Discussion point**
- Testing at USTUTT



### Lead NanoGune



# PETER schematic configuration



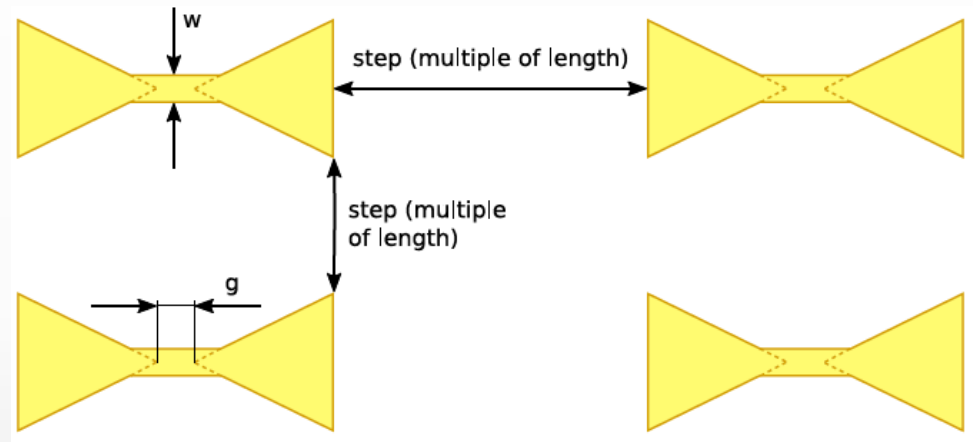
# Plasmon Enhanced Electron Paramagnetic Resonance

## PE THz EPR spectroscopy

Table 1 Sample parameters

Sample No.	resonance frequency (GHz)	g ( $\mu\text{m}$ )	w ( $\mu\text{m}$ )	step
001	210	2	1.05	1
002	280	2	1.05	1
003	350	2	0.95	1
004	420	2	0.95	1
005	490	2	0.93	1
006	210	0	0.94	1
007	210	1	1.06	1
008	210	4	1.06	1
009	210	6	1.05	1
010	350	0	1.06	1
011	350	1	1.05	1
012	350	4	1.06	1
013	350	6	0.97	1
014	490	0	0.97	1
015	490	1	0.99	1
016	490	4	0.99	1
017	490	6	1.1	1
018	210	2	0.18	1
019	210	2	0.54	1
020	350	2	0	1
021	350	2	0.55	1
022	490	2	0	1
023	490	2	0.56	1
024	210	2	0.98	0.5
025	210	2	0.99	2
026	350	2	1	0.5
027	350	2	0.92	2
028	490	2	1	0.5
029	490	2	0.97	2
030	Reference			

### ance Tests

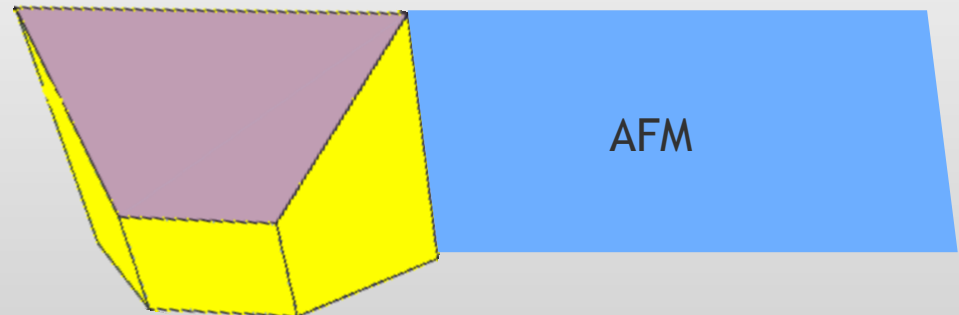
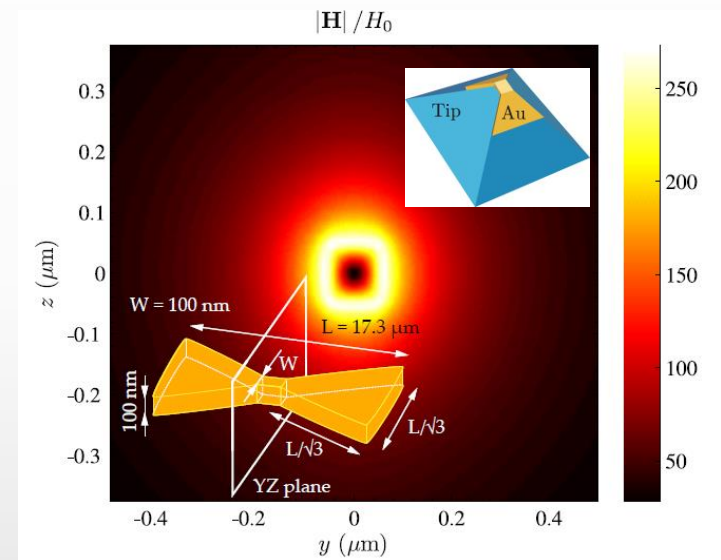


# Plasmon Enhanced THz Electron Paramagnetic Resonance

## PE THz EPR microscopy

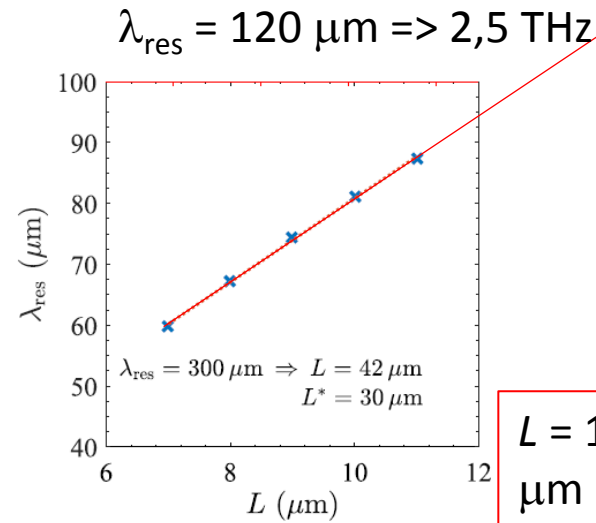
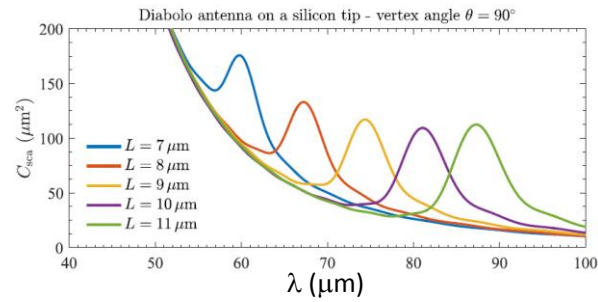
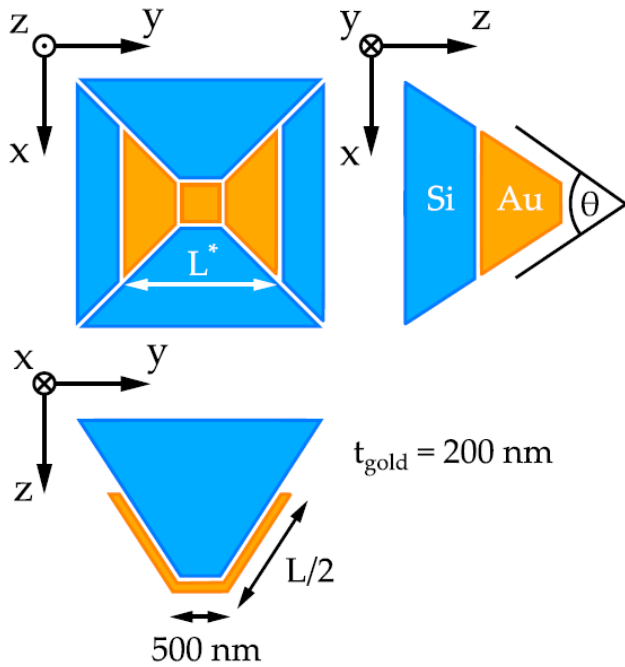
### Design and Optimization of Platform for PE THz EPR microscopy

- Design of an SPM unit
- Fabrication of cantilever tips
- Assembly and optimization of the platform
- Room temperature testing
- Low temperature testing

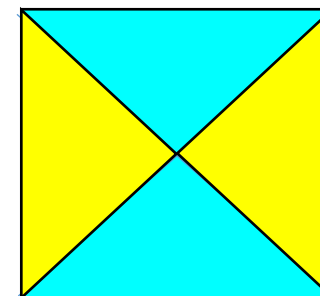
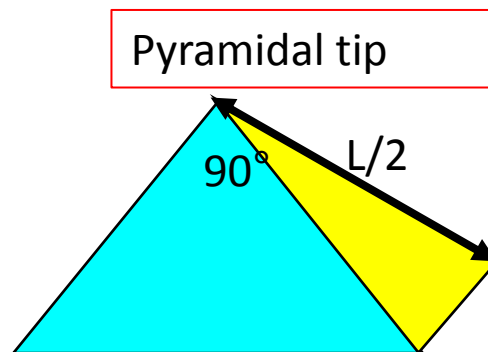
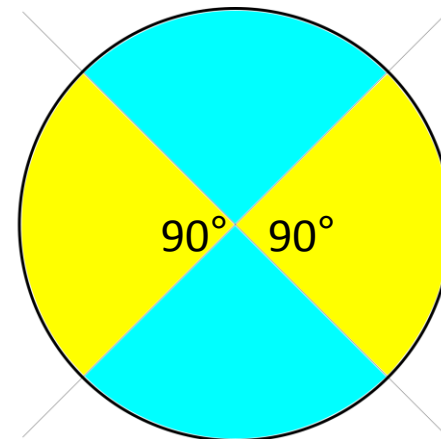
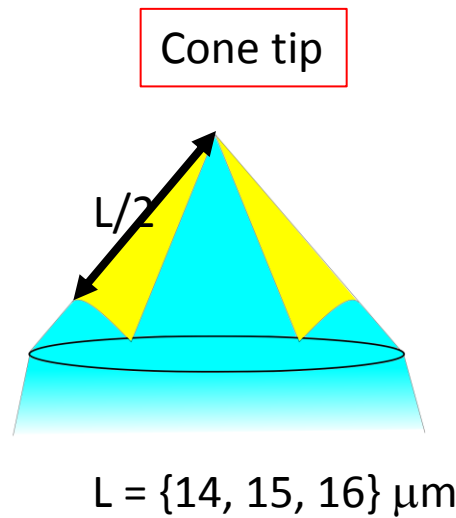
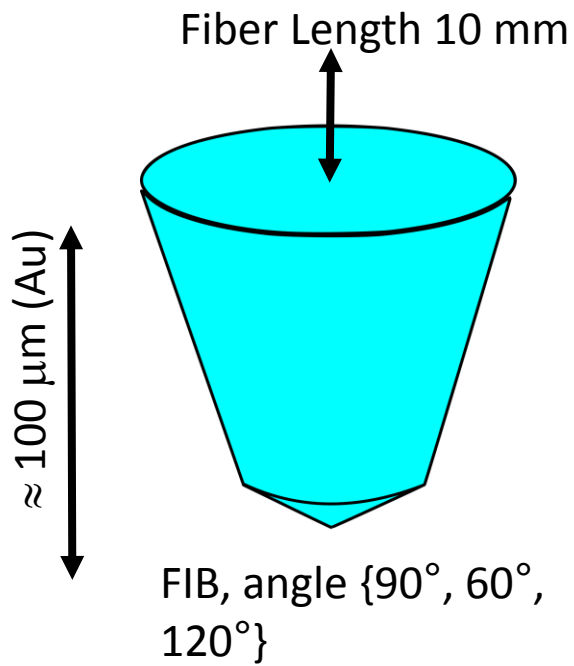


# Project PETER

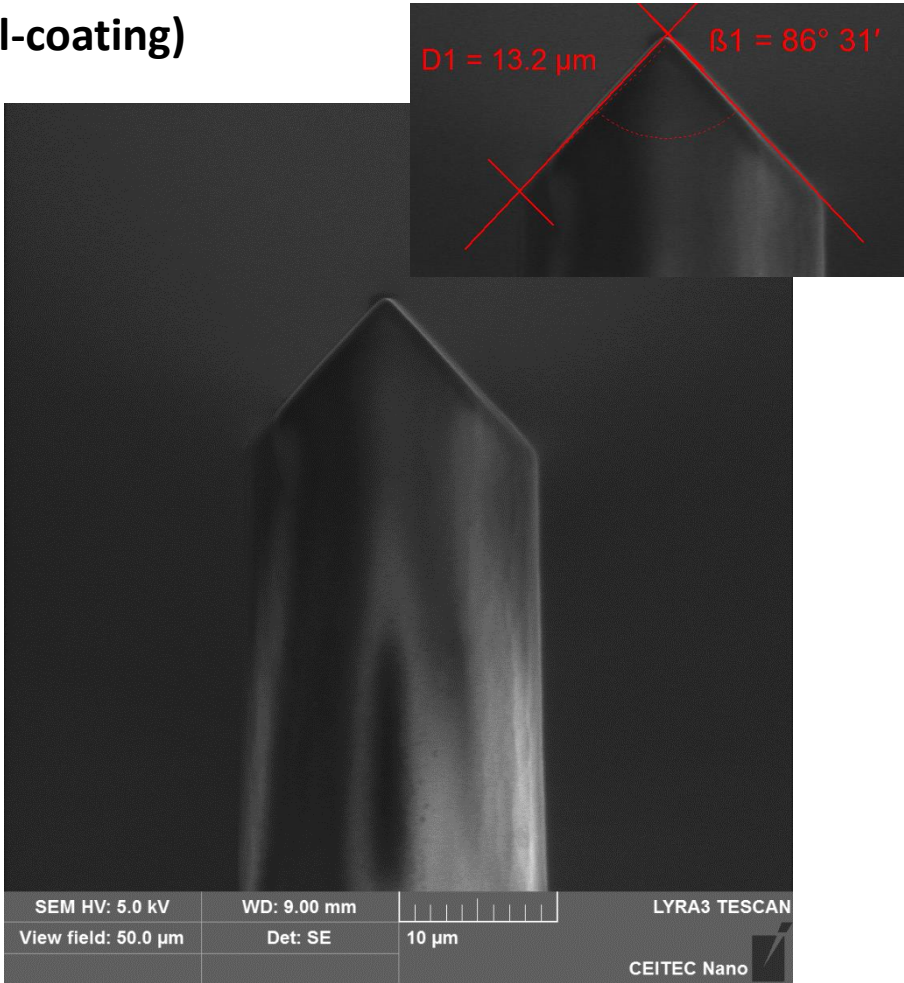
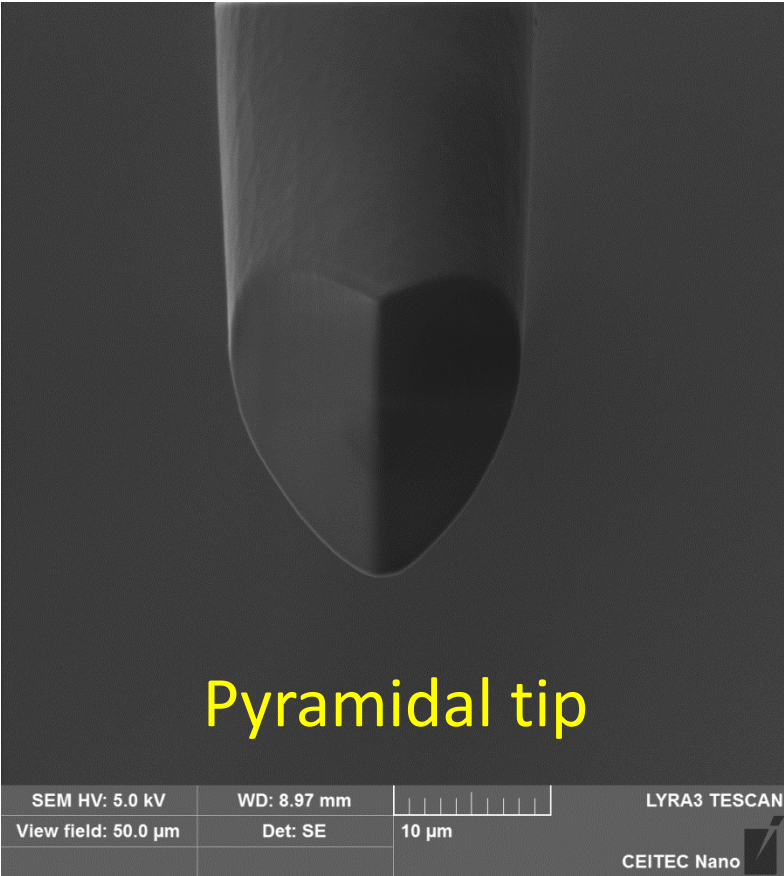
## Optical fiber tip with a diabolo antenna



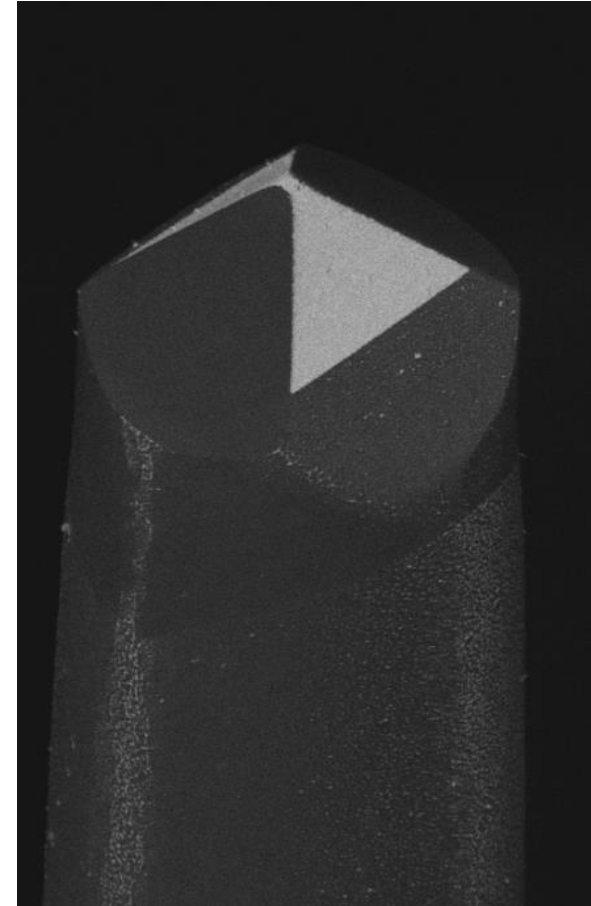
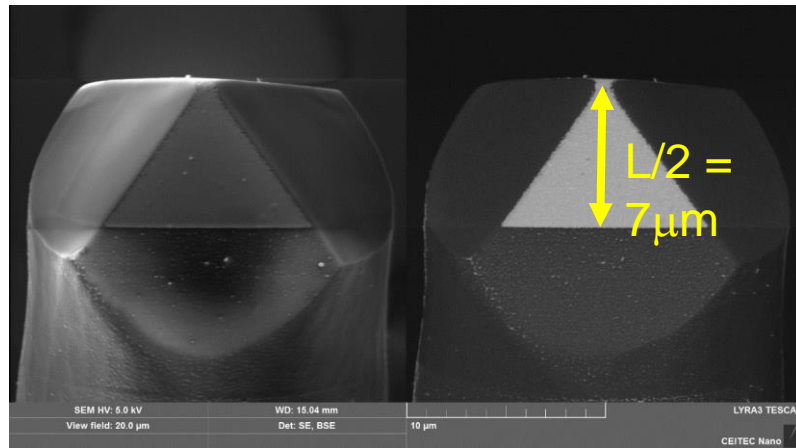
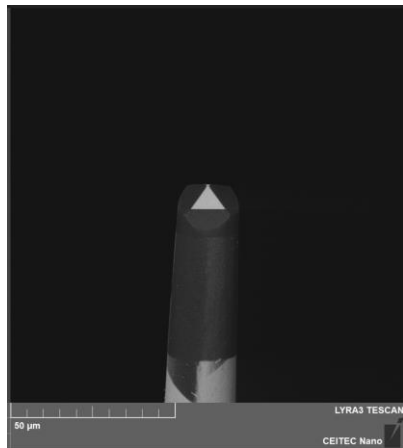
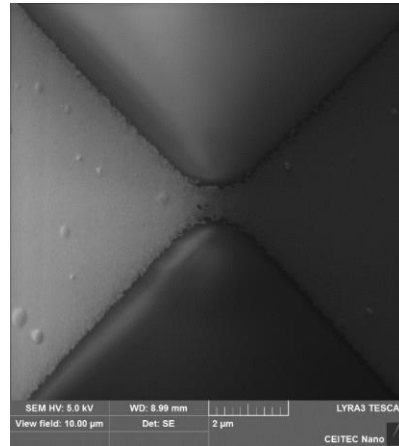
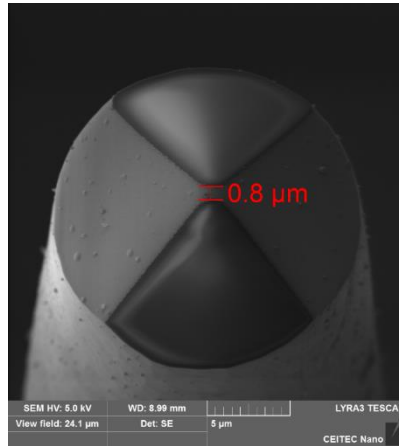
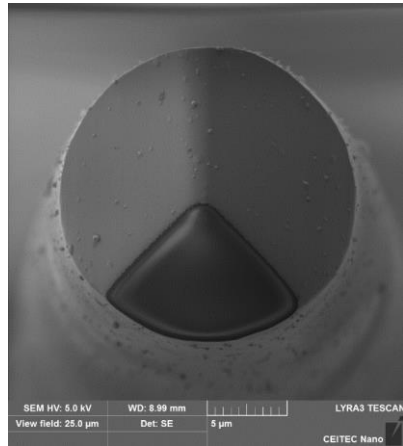
$L = 15 \mu\text{m}$



FIB milling of an optical fiber (without metal-coating)



# FIB milling of an optical fiber (with metal coating)



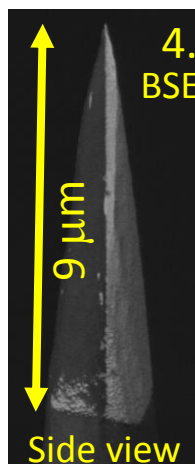
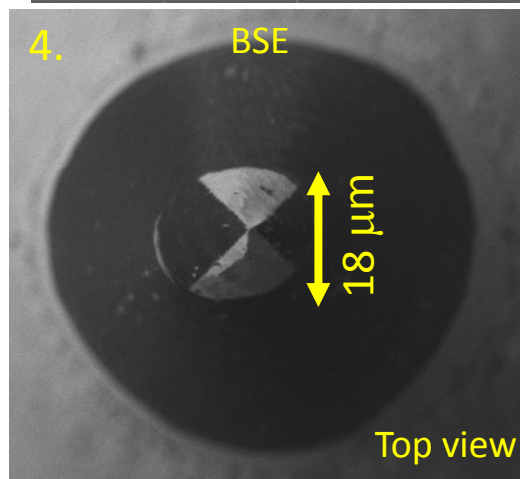
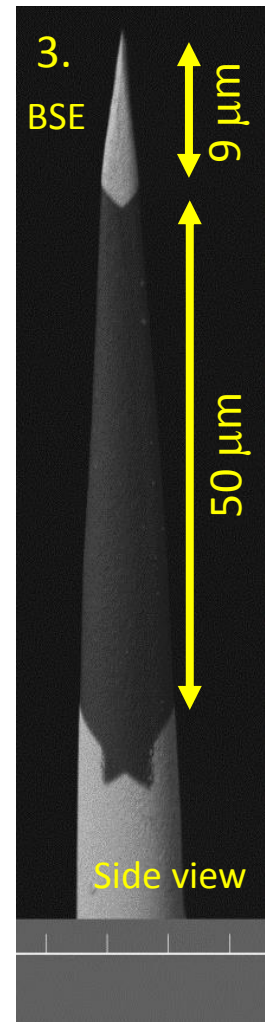
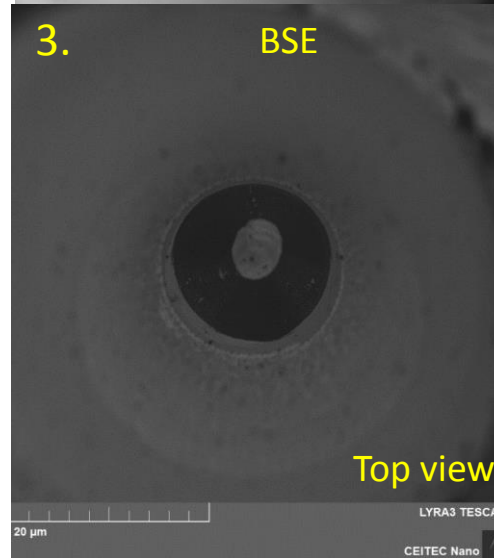
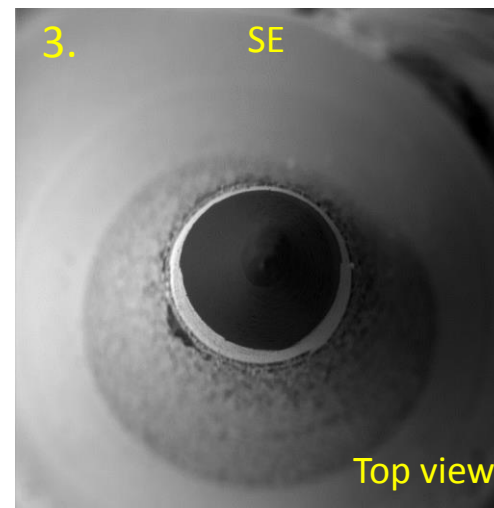
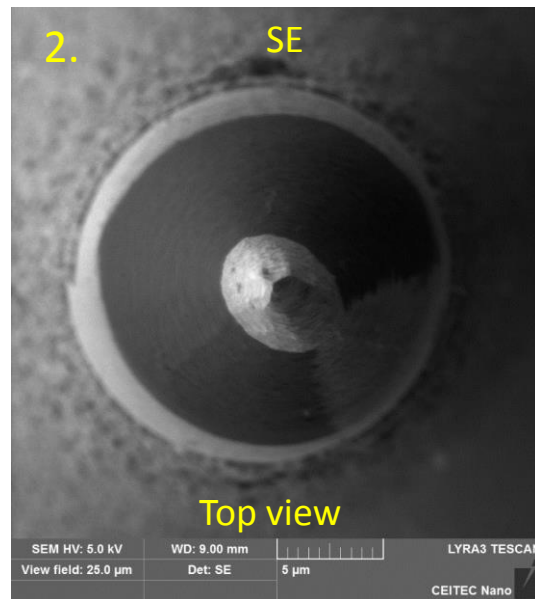
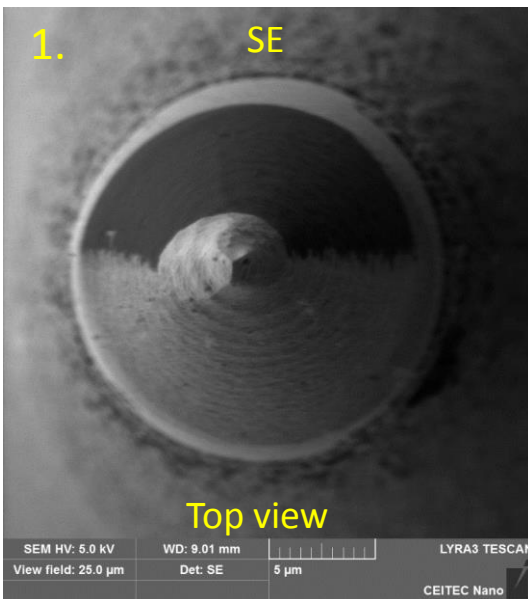


Programme  
CEITEC, S building  
Purkyňova 123, 61200 Brno

Wed 3.10.	9:30 – 10:00	Registration	Foyer S building
	10:00 – 10:30	Introduction	Tomáš Šikola (CEITEC)
	10:30 – 12:00	THz near-field microscopy based on scattering	Rainer Hillebrand (CIC nanoGUNE)
	12:00 – 14:00	Lunch break	
	14:00 – 15:30	High Field EPR - Applications and Opportunities	Graham Smith (St Andrews)
	15:30 – 16:00	Coffee break	
	16:00 – 17:30	Probing plasmons with photons and electrons	Joachim Krenn (Graz)
Thu 4.10.	9:00 – 10:30	THz near-field microscopy technique and applications with focus on aperture-type near-field imaging	Oleg Mitrofanov (UC London)
	10:30 – 11:00	Coffee break	
	11:00 – 12:00	Student presentations (4 x 12 + 3)	
	12:00 – 14:00	Lunch break	
	14:00 – 15:30	In vivo EPR imaging - methods and applications	Boris Epel (Chicago)
	15:30 – 16:00	Coffee break	
	16:00 – 17:30	Terahertz metasurfaces for advanced communication and sensing devices	Miguel Beruete (Navarra)
Fri 5.10.	17:30 – 20:00+	Poster session with banquet	
	9:00 – 10:30	Lightwave-driven scanning probe microscopy: A route to combine ultrafast temporal with sub-Angstrom spatial resolution	Jasha Repp (Regensburg)
	10:30 – 11:00	Coffee break	
	11:00 – 12:00	Student presentations (4 x 12 + 3)	
	12:00 – 12:30	Researchers' Night Brno – information	Božena Čechalová (CEITEC)
	18:00 – midnight	Researchers' Night Brno	

# 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, Implemenattion) - loss of any point is fatal



**FIB milling  
of an optical  
fiber  
(with metal  
coating)**