Notes from PETER meeting on 23.04.2020

Attendees: Vlastimil Krapek, Zdenek Novacek, Pavera Michal, Martin Hrton, Rainer Hillenbrand, Joris van Slageren, Dominik Bloos, Lorenzo Tesi, Alisa Leavesley, Elizaveta Nikulina, Bozena Cechalova, Petr Neugebauer, Tomas Sikola, Richard Wylde, Monika Larruskain

WP1

**Martin**

Tries to answer why does the Fabry-Perot resonance have a 90 degree periodicity while the antenna enhancement has a 180 degree periodicity?  mutual effect of both the Faraday effect of the EPR sample and the antenna response.

The unequal effect of LH and RH circularly polarized light is accounted for in sample absorption and sample phase shift of the THz radiation

If Faraday affect is small, 90 degree periodicity is strong, given the fact that the second polarizer is rotated by 90 degrees relative to the first; therefore get maxima when antenna is at 45 degrees because otherwise the radiation would either not excite the antenna or all of the signal from the excited antenna would be reflected by the polarizer – 45 degrees enables partial excitation and partial transmission through second polarizer

Calculations: Polarizer (WG), EPR sample (Faraday effect), antenna and substrate effects, EPR sample (Faraday effect), Polarizer (WG+90 degrees) – the 90 degree offset of the 2 WGs  get more signal at 45 degrees for the antenna

If the Faraday effect is strong (equal to that of the antennas), get asymmetric enhancements, at the 45 degrees due to Faraday effect of the EPR sample enhancing one set of 45 degree response (ie every 180 degrees). Why 45 degrees is same as above

This is a different take compared to analysis of results of Stuttgart – this would make it more difficult to understand the PS enhancement

-Comments from JvS: Faraday effect is real in EPR samples, magnitude of FE will be small – see paper Joris sent around, we would need to calculate the FE effect to know exactly

Assumed the EPR samples and the antennas had the same resonance frequency – and if the EPR sample is off resonant (only 1 calculation done) –the EPR signal was much lower

Next steps: get good agreement with the experimental data and try frequency and field sweeps of the calculations, specifically the calculation of EPR signal at fixed field, sweep frequency, and vary angle of the antennas

**Lorenzo**

Measure and simulate far field simulation with decent agreement. Simulate the near field too. The near field (assumes gold mirror below sample) is very sharp compared to the far-field resonance (transmission – does not assume gold mirror below in simulation)

Near-field: refers to the maximum magnetic field near the antennas (bridge); simulation is older one, but when the mesh size was increased (as recommended by RH) the simulation was very similar, RH finds the very narrow resonance odd; MH – if the gold mirror is included in the calculation then both the far and near field have very sharp resonances – mirror is separated by the substrate thickness (0.5 mm)

RH – adjust substrate thickness to lambda/4 to get ideal interactions  JvS – this is done as it just needs to be (lambda/4)\*n, and with lambda ~1 mm at 300 GHz, then 0.5 mm should work

Sample tested was TEMPOL 5% dispersed in PMMA spin coated on top of antennas – 330 +/- 10 nm thick film: acquire field/frequency maps (FFDMR) at 10 K & at 155 and 245 degrees (active and non-active positions respectively); Angle/frequency maps (AFDMR) at 287 GHz and 310 GHz (active and non active positions) also at 10 K

Data analysis for FFDMR: lock-in demodulation, Savgol filter, subtract standing waves, fit with derivative of Gaussian function, integration of fit, subtract to angles (done only for FFDMR)

Active get a peak at 286 GHz – agrees with simulation, background signal due to modulation, etc. Subtract the Active and inactive FFDMR – cut along diagonal along g~2 for the resonance position

RH – should we subtract OR divide  LT challenges with the modulation influences the system (phase issues cause problems (also intensity))

JvS – division is the correct way, but that the phase shifts and modulation of the standing waves makes this more difficult

Currently assume only signal is coming from the sample – now not so sure as the antenna will also have some XP signal (from Martin’s report) – the system is not as simple

AFDMR – no corrections to data, both on and off resonance, off resonant signal show no real clear signal, there could be some minor tilt of the gold back mirror, which would vary the modulation of the standing-waves

RH: Line shape comparison between on and off resonance with the antenna spectra while on –resonance with EPR sample as this could change the spectral lineshape  LT this can be looked at

AL: compare AFDMR maps on and off resonance – on the off-resonance case, should see the antenna resonance at 286 GHz and the signal resonance at 310 GHz – do you see signal for the antenna at 286 GHz? LT this will be looked at

PN: why choose 310 GHz for offset  LT 3 off resonant fields were chosen- all look similar

Spin coat on bare quartz (no antennas) – slightly thicker sample 400 nm instead of 330 nm; acquire FFDMR – preformed a LIA phase correction

**Next steps:** look at the lineshapes on and off resonance, look at maps off resonant spectra at the antenna resonance frequency, also try to look at self-assembled monolayers of radicals directly on top of the antennas – only on the antennas, comparison of active data at 207 degrees (AL suggestion) to look at antenna+EPR effect vs. no added effect; double check how the source intensity impacts the signal  DB oscillation are not on ZBD  QO cause oscillations

Frequencies USTUTT has antennas for – 150-170, 280-300, 400-430 GHz.

WP2

JvS Assembly of equipment – all is on site and ? of firmware controller updated if it is working

**Zdenek**

During LN2 test of SPM unit was able to reach 90 K, image resolution of 20 nm height was good, image was fuzzy due to boiling LN2. Probe holder was changed to PCB tuning fork since original lead wires made of kovar (NiFeCo)were magnetic; tip fabrication: glass fiber is glued to the tuning fork. Different glues were testet at RT an LN2.

Tip fabrication process> Attach tuning fork to PCB, then attach bare fiber to tuning fork (can make 10-20 /day), tip fabrication is more time consuming and is done afterwards (the PCB and tuning fork is a few cents – the expensive process is the tip fabrication) the tip fabrication is expected to take ~3 days and 5 done per cycle.

Tip shaping via iFIB with Xe plasma, gold deposition, FIB to etch gold to final shape. Fabrication is done on the tuning fork – need to replace the fork, tip and PCB as one unit if the tip is broken.

RH: concern of roughness on tip structure – ZN: can try to polish the tips – maybe it is possible, RH is concerned the process is too slow – smoother will take longer to manufacture – concern that we have not seen signal from a single antenna before – therefore we should try to make the best antenna possible to make sure the antenna is not the reason why we do not see signal – ZN maybe try post-processing polishing (high current to shape and low current to polish as a step)

TO DO: Try to make a cross-section and see how do the grooves compare to the gold thickness

System has good height resolution <20 nm and xy is better than 1 um, with the tip tested

Geometry of tip apex? – pyramid vs. ½ sphere (RH ?) – diameter of apex? – 1 um, signal will be significantly affected by this (actually larger signal with larger tips) - ? of tip S/N

See signal of calibration grid at USTUTT – firmware update should have been solved  so SPM unit should be fully operational

Operating in tapping mode – vertical oscillation amplitudes ~10s nm

Orientation of antenna – can be anything because of rotating wire grids from TK

The tuning fork needs to be quartz with metallic electrodes.

Parameters:

Smoother surfaces on the tip, tuning fork, pyramid or ½ sphere (RH thinks ½ sphere would be better), optics radius should be determined for ideal operation (can be done once the geometry has been confirmed); generally larger tip are probably better (less enhancement but more volume – and enhancement is proportional to r-1, while volume is proportional to r3)

1 um is final goal – try to start out on a larger diameter dip – say 5 or 10 um to start.

Next steps:

BUT-NanoGune: Improvement of the tip morphology, fabrication of tips of different shapes and dimensions (First: to discuss how to proceed jointly on this task).

**Alisa**

All in favor of heterodyne detection + source, in favor of 320 GHz – still debating the bandwidth: add no cryogens necessary to run the system as a + for heterodyne detection

Discussion over 12 vs 20 GHz bandwidth – JvS 12 GHz will work for organic radicals, PN how well tuned are the antenna resonances to match within the bandwidth? LT we should just get a bunch of antenna resonances that have 5 GHz resonant offsets across the full bandwidth of the source to account for shifts. RH concerns with resonant frequency variation due to the fabrication process (ie it is not possible to guarantee tip a and b will have the same performance even if they are designed the same – this can be due to cracking of metals, adhesion angles, etc.) RH also concerned with how the tips will perform at cryogenic temperatures, concern for cracking of gold

Tip discussion part 2: RH possibility of using off-resonant antennas by using fibers with effectively infinitely long sides relative to the wavelength of light making the antenna broadband also if this off resonant affect will work for the magnetic field enhancement. RH how does the tip /probe exchange work (how easy is it) and how will it be done at cryogenic temperatures. How long does it take to exchange samples AL – at least 2 hrs

USTUTT is open now, with social distancing applied. ? of when Martin can start in USTUTT in a few weeks; need to get housing for him, ? for Martin on when he wants to come? – he will need paperwork to get permission to leave Czech Republic

No need to wait for heterodyne detection scheme to arrive; still need to run RT, cryo tests, etc for both EPR and microscopy

Sample systems – particles  crash of tip, current TEMPOL samples  low signal, ferromagnets with g=2, pellet of this via USTUTT, BUT to make patterned ferrites for microscopy tests

AFM can be remotely operated; move tip and then acquire the EPR spectrum, note pixel location and then acquire software, how is the image put together – EPR software is fully automated; suggested to acquire images at fixed field (may have issue of standing waves, alternative longer field swept measurements per pixel)

WP3

Bozena – May 12 – training on how to apply and deal with amendments and extensions for H2020

Extension – expect no extra money, but we will get the extension – need to have the extension

Workshop – Y/n, funds saved could be applied to personnel costs, 10 speakers – hotel reservations made and cannot get money back (save money for flights 5-10k€)- expect savings of 15k€ if cancel or have on-line, spent 2K€ that will be ‘lost’

-Plan to keep it face-to-face but push it to March/April 2021 – get definite dates by mid-June

Budget discussion – second part of Alisa’s (TK) presentation