THz Surface Plasmon excitation without a coupling device

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OUTLINE:

- **Useful plasmon properties in THz?**
- **SP field distribution, SP velocity**
- **SP excitation *without a coupling device*. Noncollinear Bragg reflection spectra**
- **SP excitation with a prism coupling. The same Bragg reflection.**
- **Reflection of a particular grating groove**
- **Conclusion: THz SP is a leaky wave, grating is selective to a surface mode**

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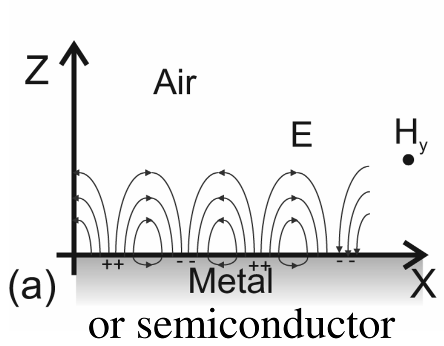
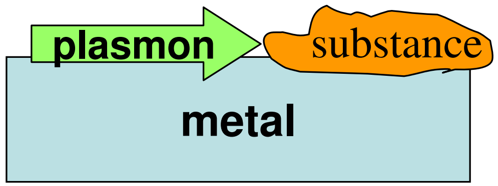
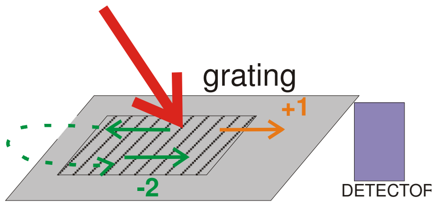
Motivation





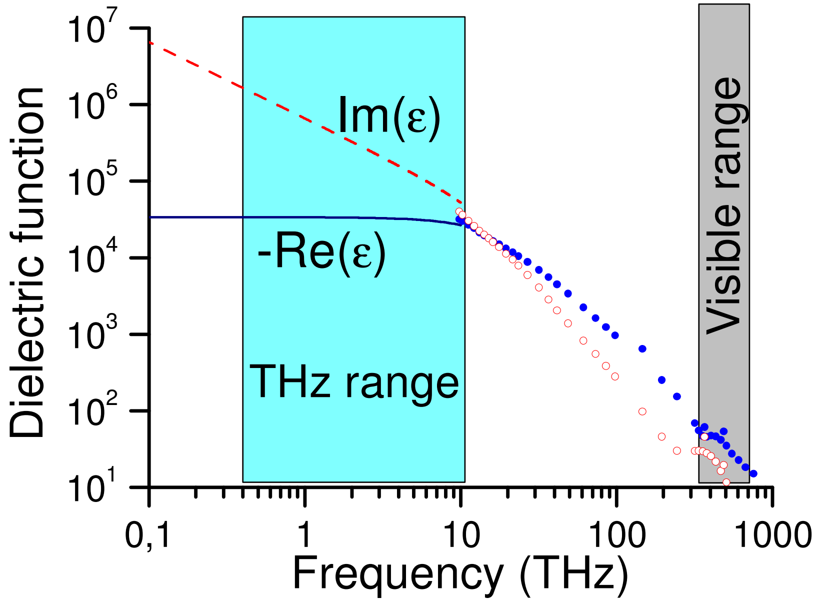


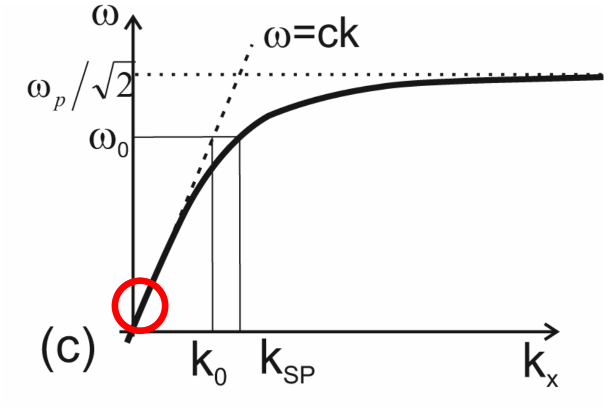
1. Plasmons are known to have high surface sensitivity from vis. to mid. IR ranges
2. THz range is requested for applications. We should overcome problem with THz SP **field localization**
3. Devices based on THz SP are not obvious. We start with simplest **Bragg mirror**
4. THz Bragg gratings are requested in BWO-like devices

Response of metals

metal response obeys Drude model

$$\varepsilon(\omega) = 1 - \frac{\omega_p^2}{\omega^2 + \gamma^2} - i\frac{\omega_p^2 \cdot \gamma}{(\omega^2 + \gamma^2)^2 \omega}$$





For "ideal conductor" surface mode is not possible, it is not bounded to the surface.

THz: $\varepsilon \sim -10^4 + i \cdot 10^6$, ideal or not ?

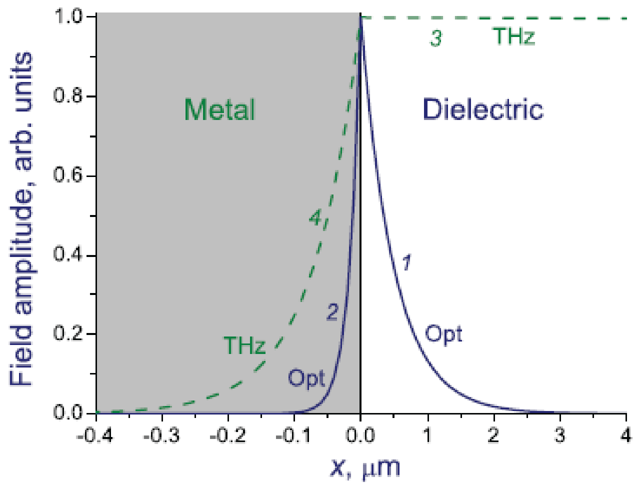
The origin of the problems

ω<<ω$_p$, $\varepsilon_1 \rightarrow \infty$,

$$n(\omega) = \sqrt{\frac{\varepsilon_1 \varepsilon_2}{\varepsilon_1 + \varepsilon_2}} \quad k_{SP} \approx \frac{\omega}{c}\left(1 - \frac{1}{2\varepsilon}\right)$$

$v_{plasmon}$=c

99.9..% of TSP energy is in the air



Plasmon and bulk wave parallel to the surface are the same?

Oxides or water thin layer improves localization but not enough

$$\alpha_{SP} = 2\frac{\omega}{c}\mathrm{Imag}(n_{SP}) \approx \frac{\omega^2}{\omega_p^2}\frac{\Gamma}{c}$$ ≈ 10^{-3} cm^{-1} – absorption during propagation

$$d_{air} \approx \frac{2c\omega_p}{\sqrt{2\Gamma\omega^3}}$$ ≈ 10 cm – localization at the surface

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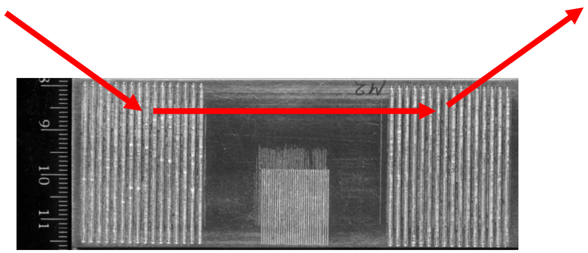
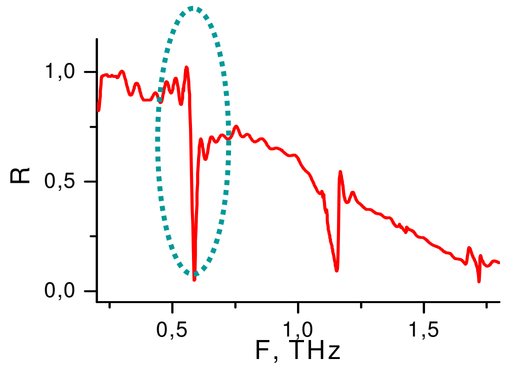
Traditional methods of SP excitation

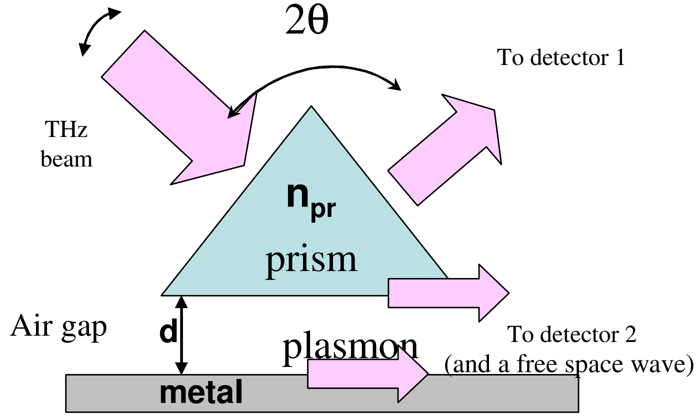
grating



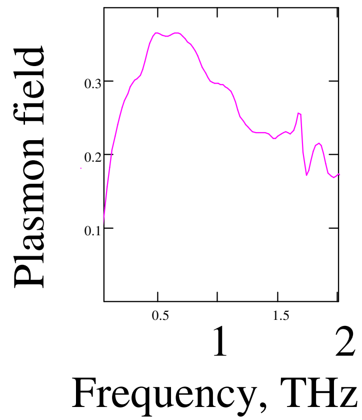
$$\vec{k}_{SEW} = \vec{k} \cdot \sin(\theta) \pm m\vec{q}$$



prism



$k{*}n_{pr}{*}\sin(\theta)=k_{plasmon}=\omega/c$



$n_{pr}{*}\sin(\theta)=1$ in a broad frequency range!
But it is ATR condition

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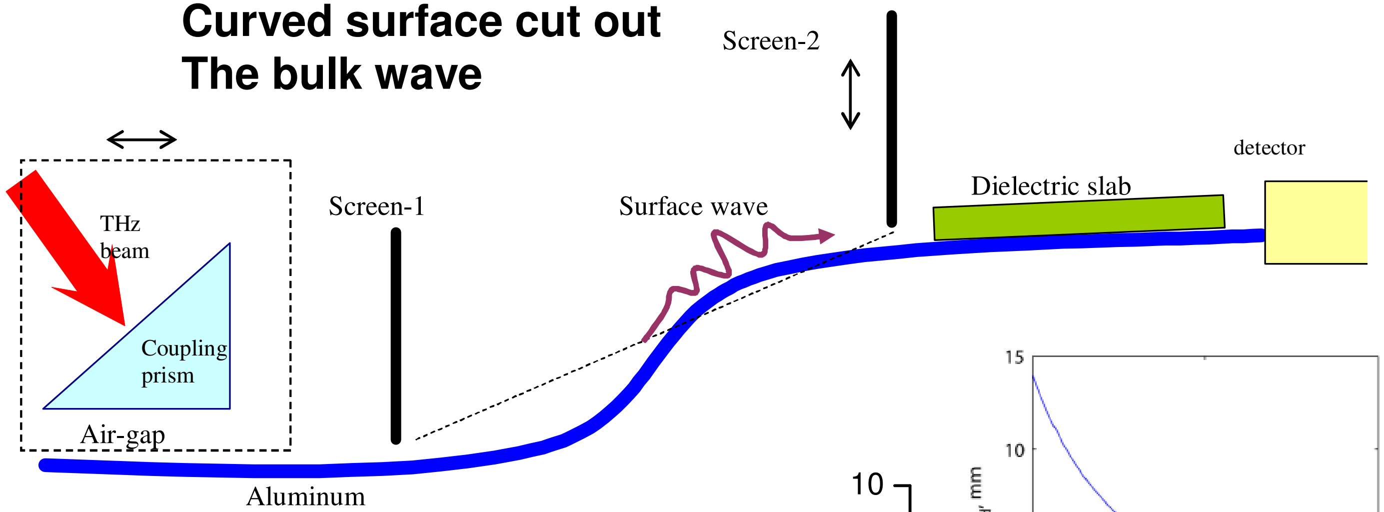
Field profile measurements

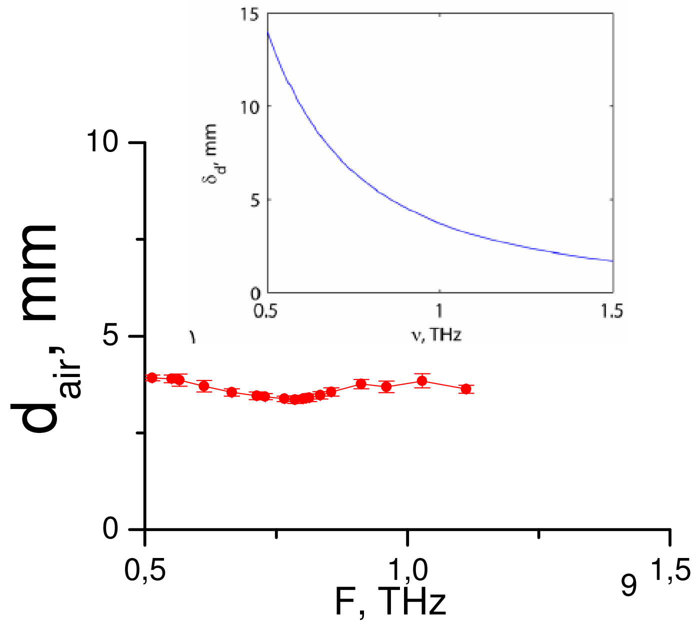
Curved surface cut out
The bulk wave



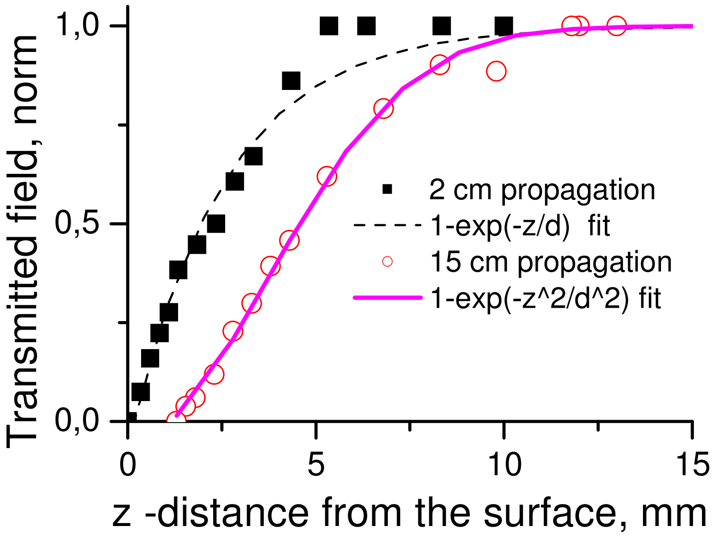
TDS allows velocity measurements Vsp=c±2%

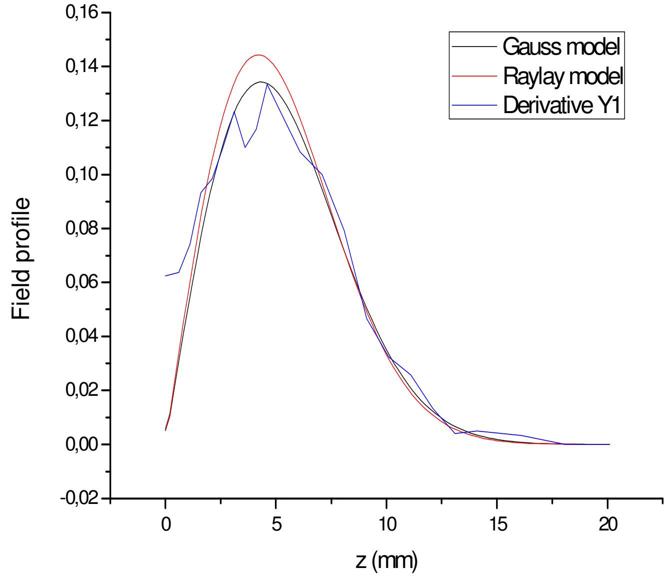
Screen is used for z localization measurements.

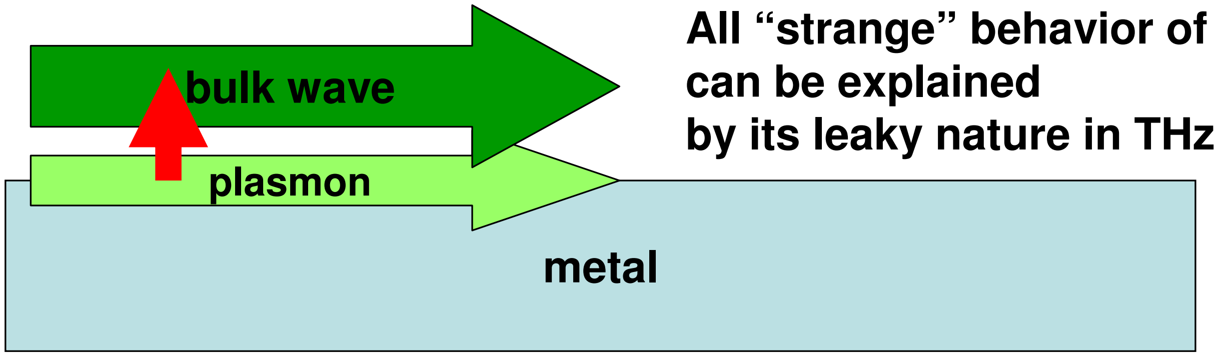
Bulk and surface waves are launched, they may be separated on the curved surface



Plasmon field distribution







All "strange" behavior of SP can be explained by its leaky nature in THz

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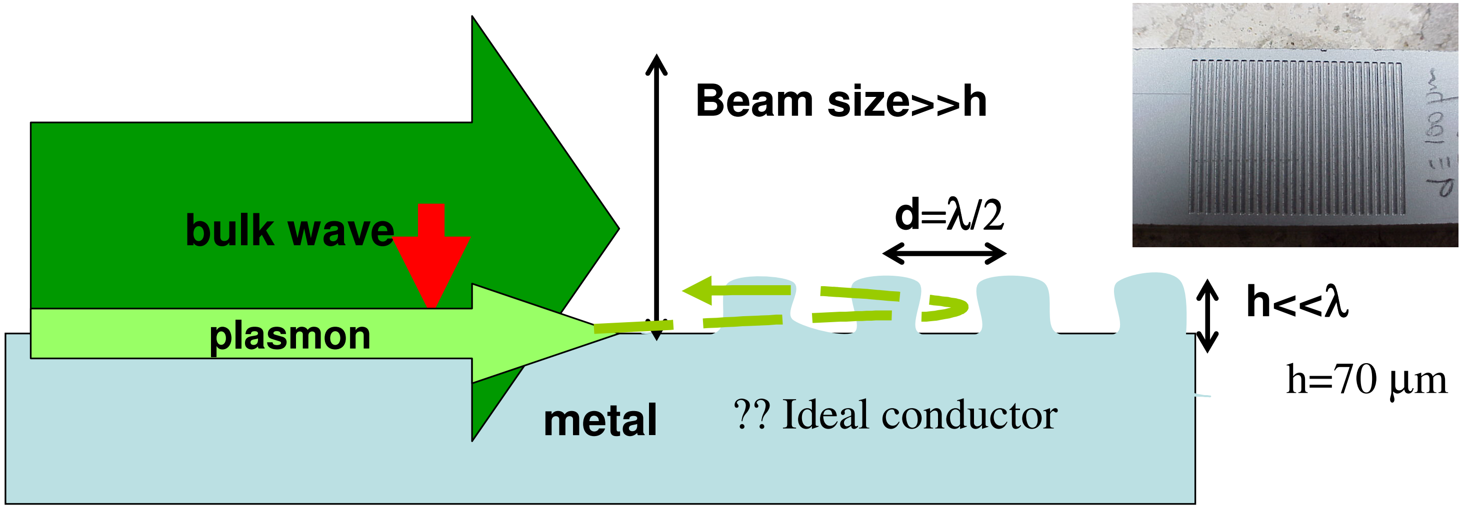
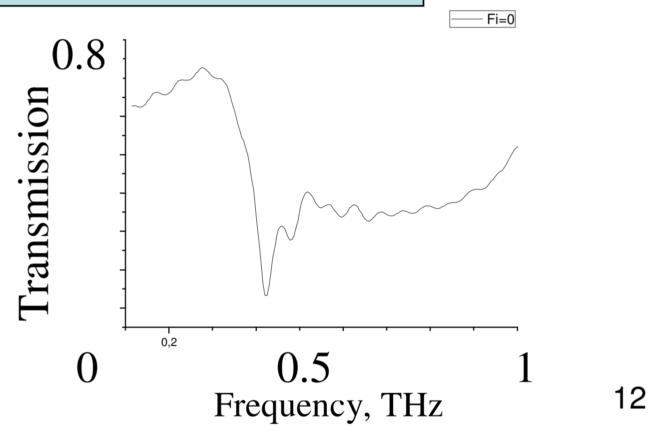
Plasmon launching without coupling device!?

Since $v_{sp}\approx$ c and $d_{air}\approx$"beam size", opposite process is possible:



To be sure that we excite SP we need some process specific only to surface waves.
Bragg reflection on the shallow grating may be efficient for the surface wave only



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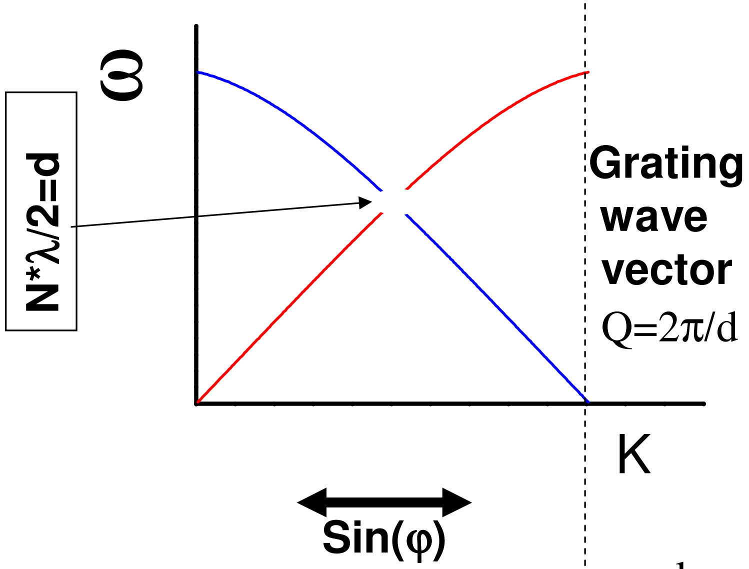
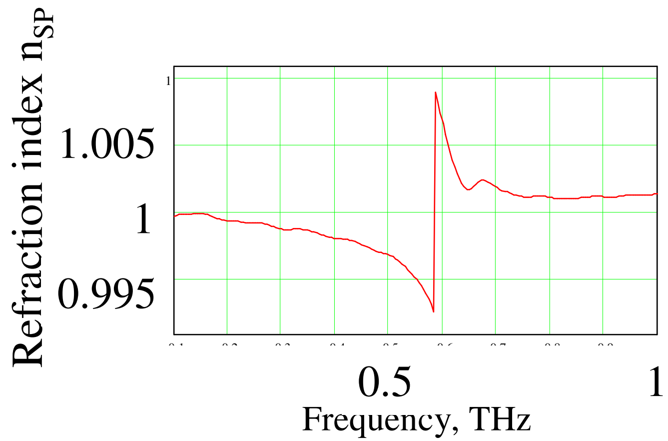
Grating influence



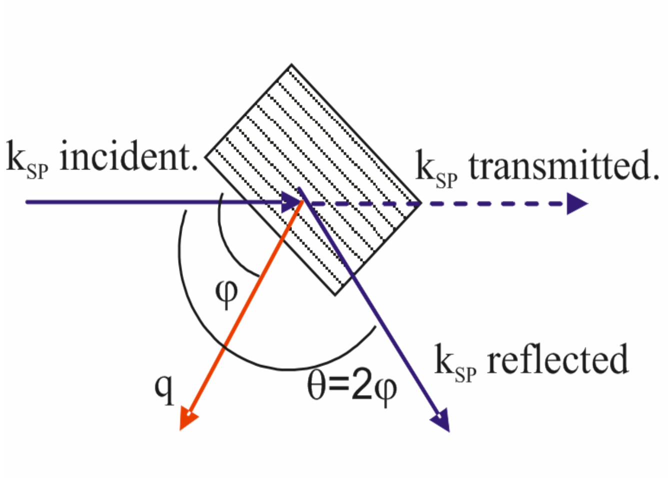


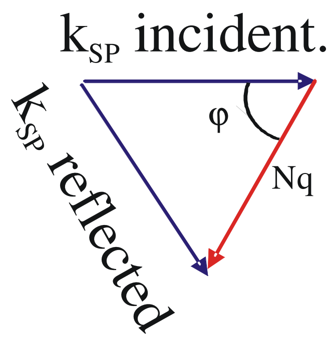
$k_{SP}=n_{SP}*\omega/c$

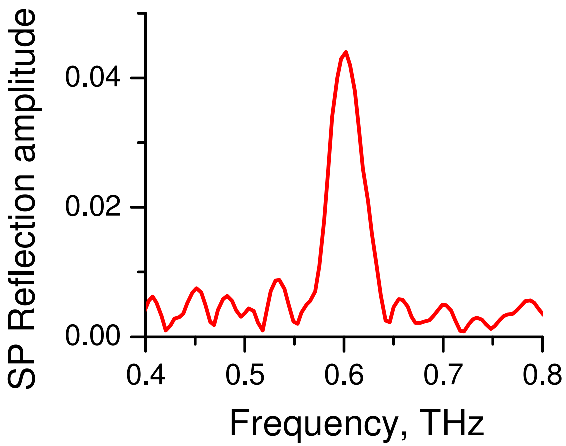
a) What are plasmon parameters in the vicinity of bandgap?

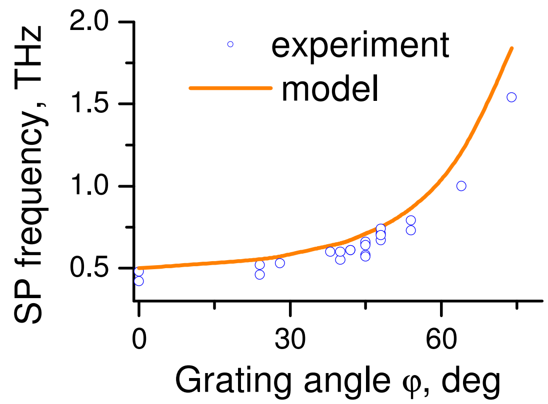
b) The width and efficiency of reflection band?

We can detect *reflected SP* in a particular direction. Bragg frequency is tunable









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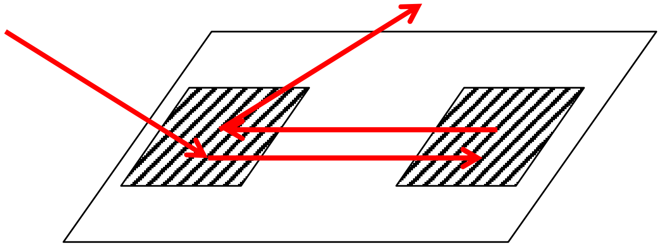
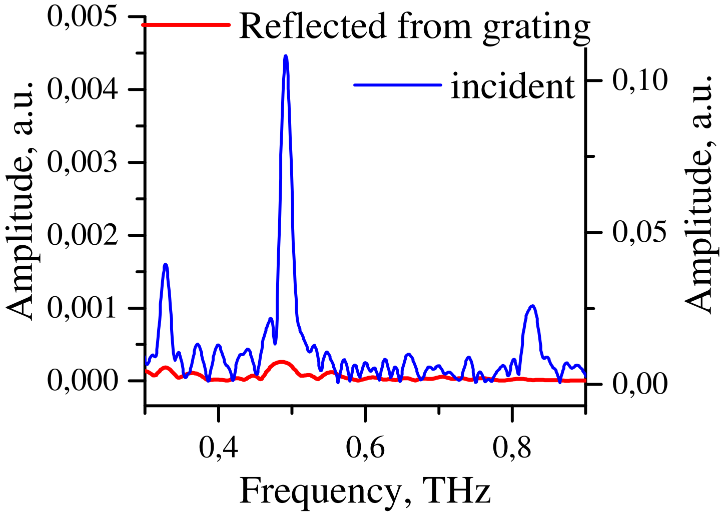
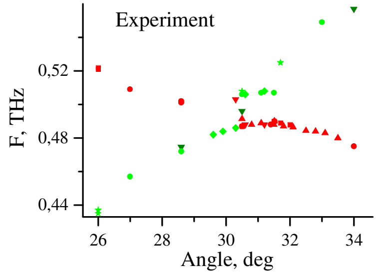
Will we observe Bragg reflection for a "traditionally" excited SP?



Grating coupler (and reflector),
-No limitations on d_air, "true SP" is excited
– Bragg reflection is very weak





A. V. Andreev, M. M. Nazarov, I. R. Prudnikov, A. P. Shkurinov, JETP Letters **90**, 177-180, (2009).

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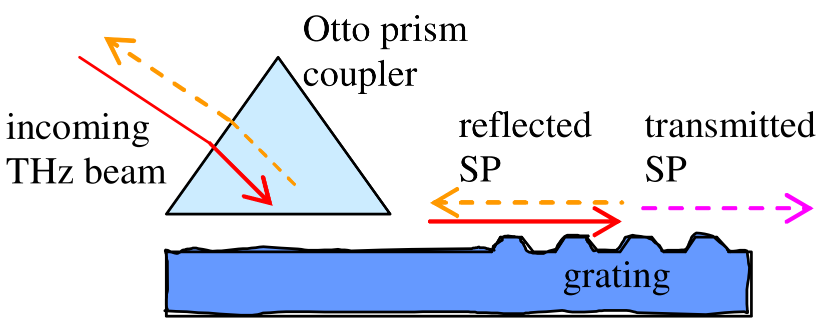

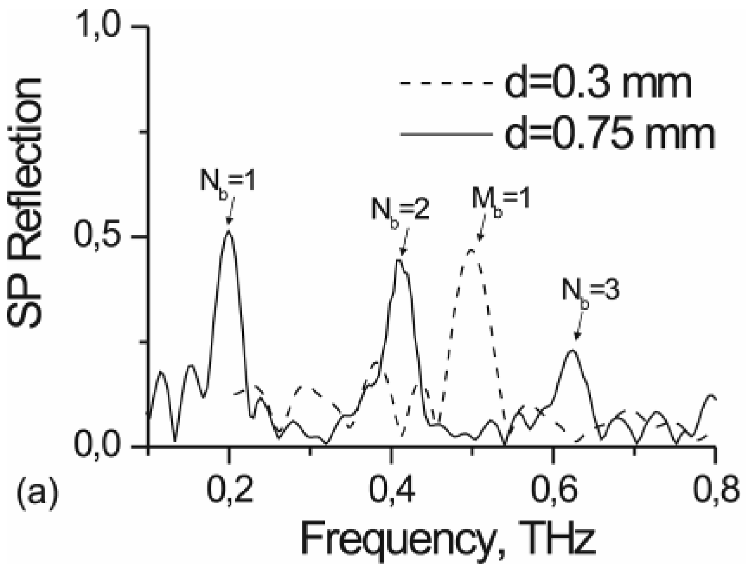

Prism coupler (broadband SP!),
-Some limitations on d_air, "SP" and bulk wave are lounched
– Bragg reflection is noticeable, we could optimized the grating (reflector)

M. Nazarov, A.A. Angeluts, A.P. Shkurinov, J.L. Coutaz, IRMMW-THz 2010 technical digest, We-P.46, (2010).

Optimized Bragg reflectors parameters for THz SP

profile	h, microns	d, mm	Reflection value	Frequency, THz	width, GHz
triangular	75	0.3	0.1	0.5-0.8;1.1	40
Sine square	140	0.75	0.15	0.2;0.4;0.6;0.8 ;1	30
Sine square	120	0.75	0.05	0.4	
rectangular	80	1.2			12
rectangular	60	1.2	<0.05		

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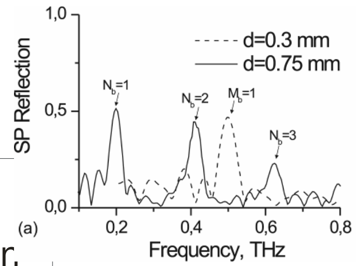
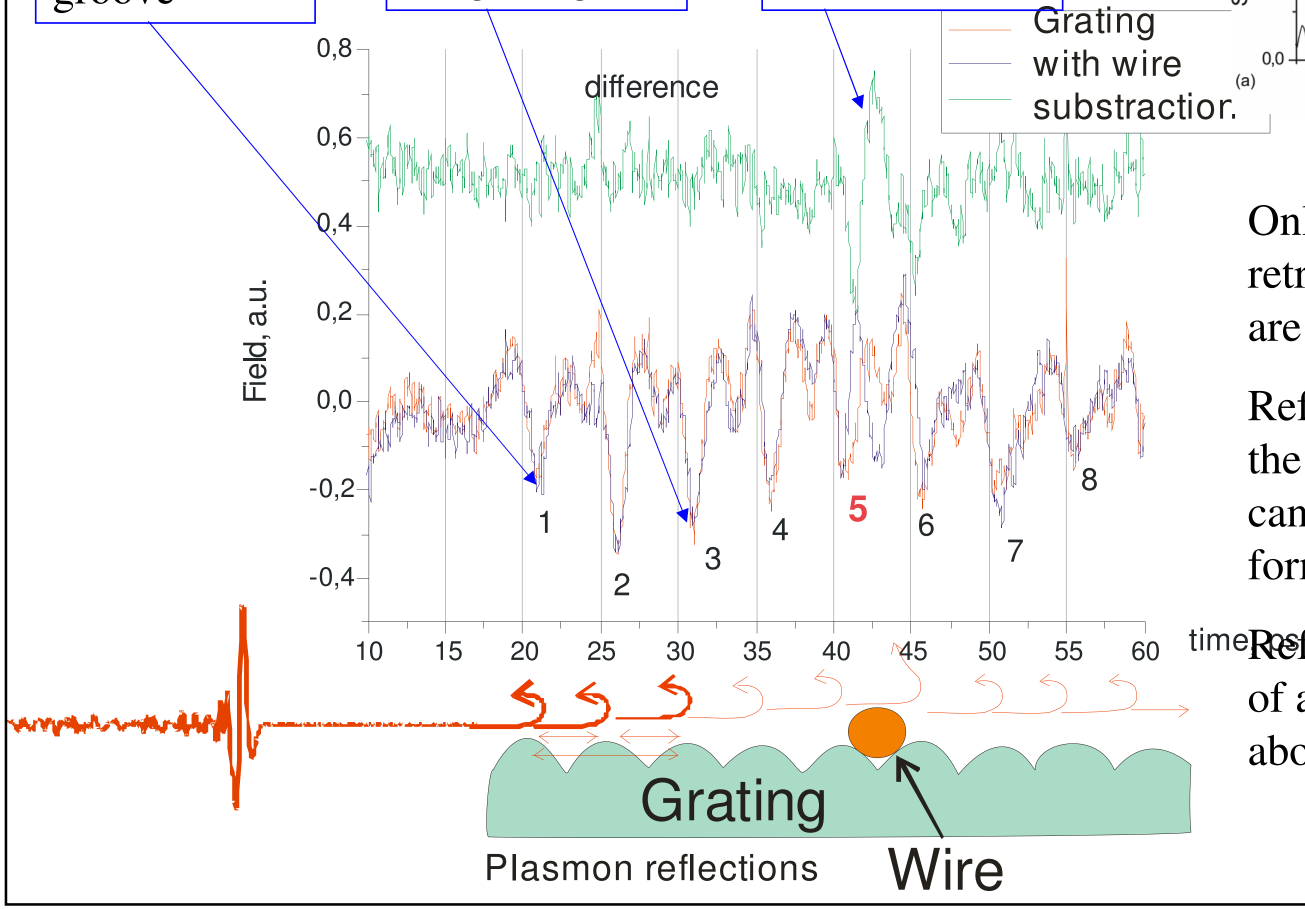
Time-domain data of short pulses is very informative

Reflection from single groove

Multiple reflections on the grating

Reflection from a “defect”





Only two retroreflections are important

Reflection from the 9-th groove can not escape form the device

Reflection value of a single step is about 0.2

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Conclusion

In general THz SP localization is weak.
Coupling/outcoupling device is not necessary

Bragg reflection on shallow grating is a good indicator of a surface mode.
Only plasmon mode is sensitive to thin structures on the surface

At THz frequency range surface plasmon on metal surface and bulk EM wave along the surface convert one to another in each point of propagation.