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9. Light whiskers

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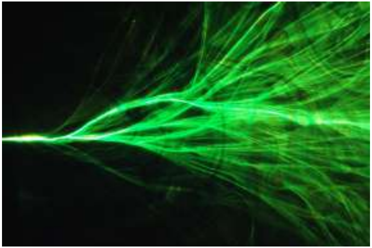
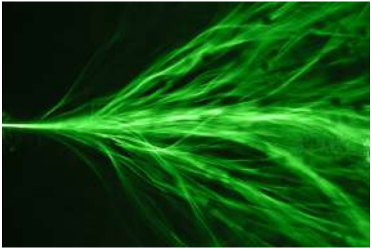
9. Svetelné fúzy

Keď laserový lúč vstúpi do mydlovej blany pod malým uhlom, vo vnútri blany sa môže objaviť rýchlo sa meniaci vzor tenkých rozvetvených svetelných stôp. Vysvetlite a preskúmajte tento jav.

Light Whiskers

When a laser beam enters a soap film at a small angle, a rapidly changing pattern of thin, branching light tracks may appear inside the film. Explain and investigate this phenomenon.



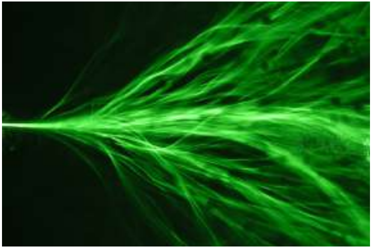


References

1. A. V. Startsev, Yu. Yu. Stoilov: *A miracle happening to a laser beam in a soapfilm*
   Quantum Electronics **33** 380-382 (2003).
2. Yu. Yu. Stoilov: *Laser beam in a soap film,*
   Physics-Uspekhi **47** 1261-1270 (2004).
3. A. Patsyk *et al.*: *Observation of Branched flow of light*
   Nature **583** 60 (2020).
4. Supplement to [3]

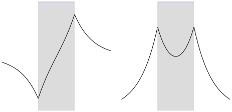
What is known from experiment

1. Light beam split into a set of narrow branches odf length ~ 3 mm
2. Branches cross each other but do not interfere
3. Transversal width is very small in comparison with "standard" beams ("transversal localization of light??")



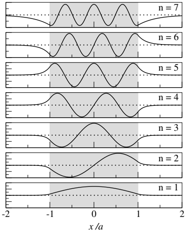
Two possible interpretations

(1) Polaritons



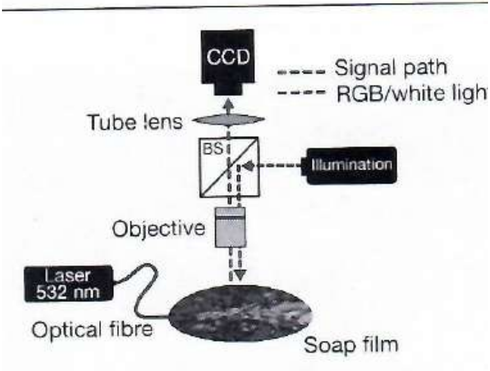
- excited at two surfaces
- only for one specific direction of incident lingth
- quite difficult to excite, because of difficult coupling with incident light - excited usually at metal-air interfaces“

(2) Guided modes



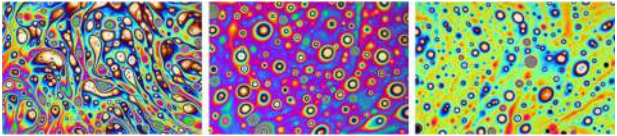
- known from e.g. optical fibres
- difficult to couple with incident light
- exist in any dielectric layer

Setup of the Experiment



Properties of the Soap layer

First, we need to know in which medium light propagates. Typical thickness: 500 nm. Thickness must be measured by interferometer (Fabry-Perrot interference at thin layer)

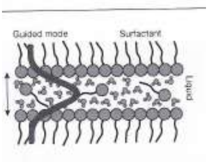


Reflected light

- Observation of interference pattern
- Reconstruction of thickness
- attempt to find mean thickness and possible spatial correlations

Idea

1. Thin soap layer has refractive index $n > n_{\mathrm{air}}$, therefore supports guided modes. Only the first one is relevant.



2. The thickness of the soap layer varies randomly
   this is crucial - no whiskers where observed in layer located at flat substrate
3. The light bounded in the layer "feels" random potential
4. Waves in random potential have troubles to propagate

We observe wave phenomena
Interesting: whiskers remain narrow, there is no diffusive broadening!

Relevant parameters

1. laser wavelength $\lambda = 532$ nm
2. long lifetime of the soap layer (several minutes)
3. thickness of the layer - comparable to λ (100-500 nm)
   it changes along the layer (will be measured by interference)
4. effective refractive index: random variable $n_{\rm eff}$ with:
   - mean $\overline{n}^2$
   - variance $v_0 = \sqrt{\langle n_{\rm eff}^4 \rangle - \overline{n}^4}/\overline{n}^2$
     small, of order of a few per cent
   - correlation length ℓ_c
     long, much larger than λ ($90 - 350\ \mu$m)
5. the length of the trajectory light travels in the layer

Source of light

Laser. The light is guided by optical fiber and coupled with the layer.

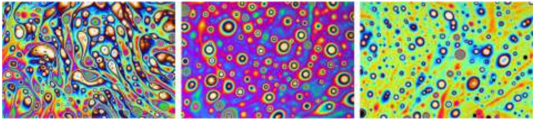
Diameter of fiber: $\sim 3\ \mu$m

Thickness of the layer: $\sim 0,5\mu$m

Stoilov reported whiskers that light might be couled with layer also if laser beam impinges surface under large incident angle ($> 80^o$)

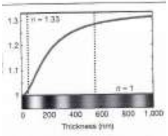
Soap layer

Typical thickness: 500 nm. Thickness must be measured by interferometer (Fabry-Perrot interference at thin layer)



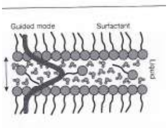
Reflected light

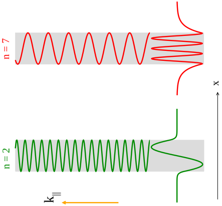
- Observation of interference pattern
- Reconstruction of thickness
- attempt to find mean thickness and possible spatial correlations
- from known thickness, find n_{eff}

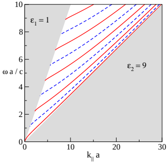


as a function of possition and reconstruct its statistical properties

Soap layer







Example of two guided modes and dispersion relation. Requirement of continuity of fields at the boundar enables us to determine effective refractive index if the width is known (from interferometric measurement).
In our case, only the first mode is relevant - higher modes require thicker layer.
Since thinckness is random, n_{eff} is random, too.

Possible output

- Experiment
- Observation of branched flow
- correlations between parameters of layer (thickness, material, randomness) and form of whiskers (if observed).

2. Numerical simulations

Solving of Helmholtz equation for the spatial distribution of the electric intensity

$$-\lambda\Psi + k_0^2\left[\overline{n}^2 - n_{\rm eff}^2\right]\Psi = k_0\overline{n}^2\Psi$$

$\Psi(x,z)$ ... electric field at a given point as an input, one has to calculate $n_{\rm eff}(x,z)$ from known thickness

I think that numerical work is quite difficult. Contact me if you want try.
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