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Rarefied gas flows in microstructures with high-frequency oscillating elements

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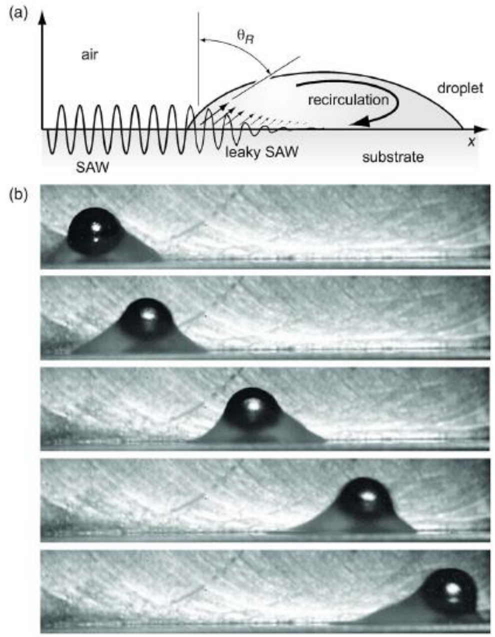
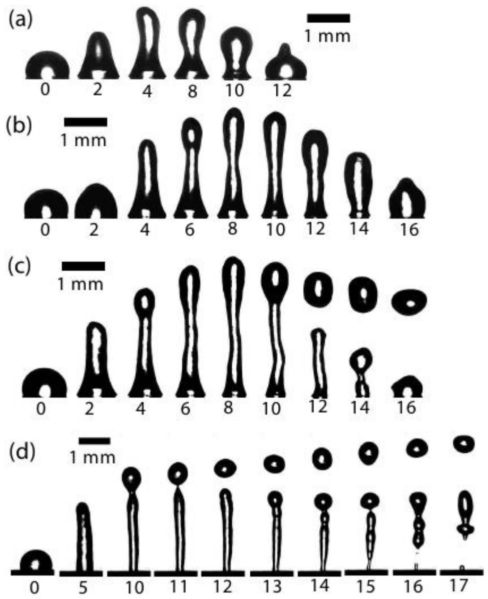
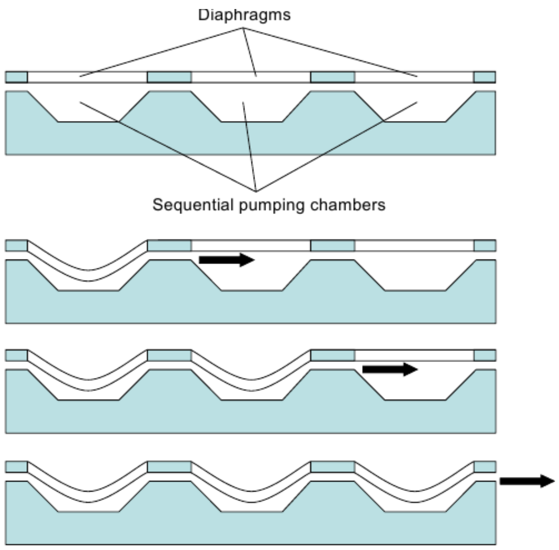
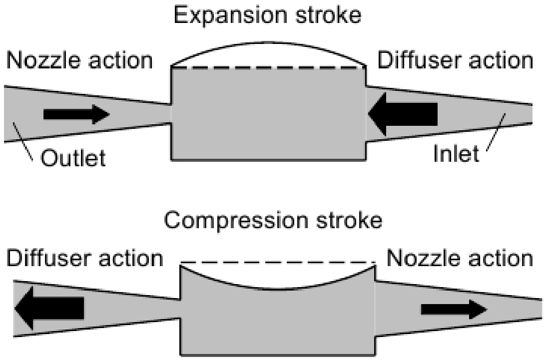
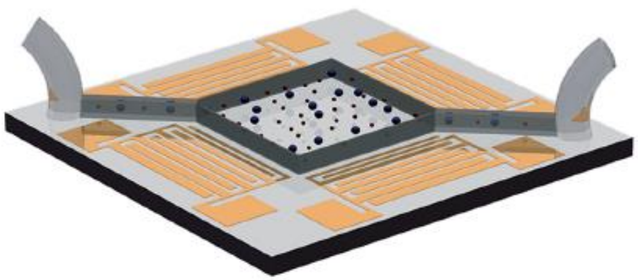
Existing applications of oscillations in MEMS



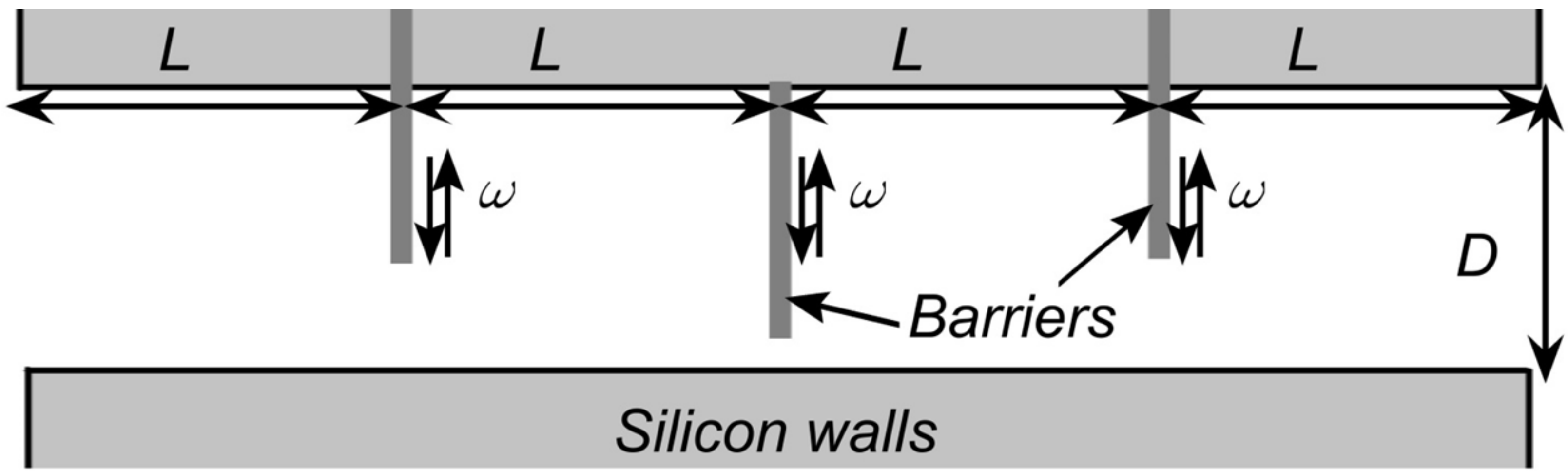


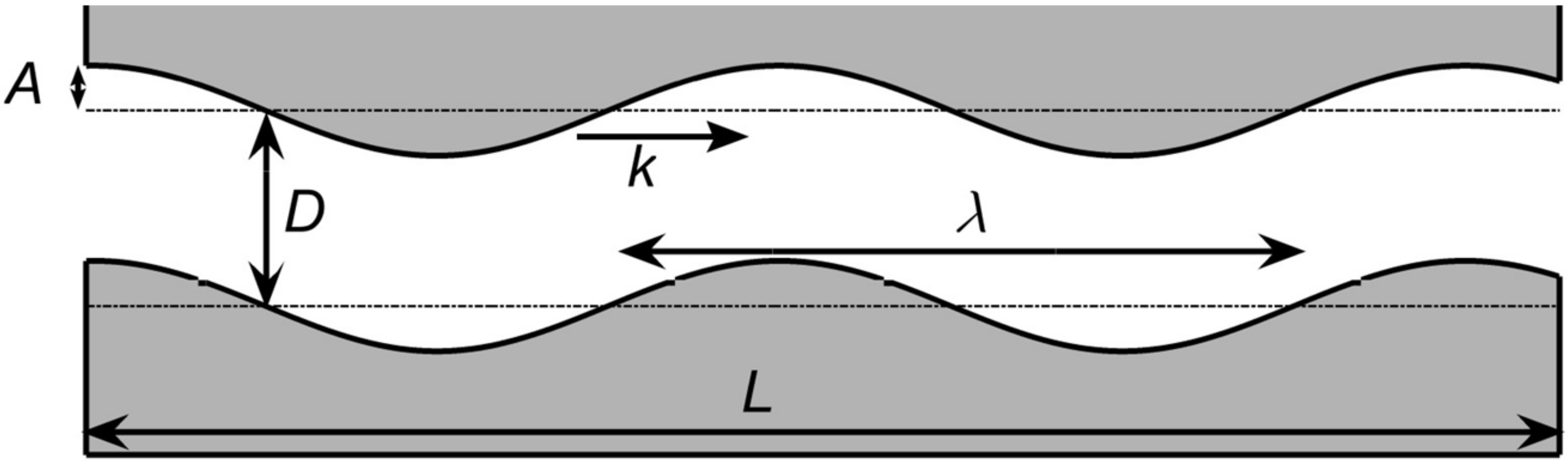






Two studied problems





Separation effect in microchannels

Free molecular flow

$(Kn = \lambda/D > 10)$

Natural Knudsen diffusion

Separation factor $\alpha \equiv \frac{J_B}{J_A} = \sqrt{\frac{m_A}{m_B}}$

Molecular flux J between to reservoirs is related to passing probability P as

$$J = P \cdot \frac{(p_2 - p_1)}{\sqrt{2\,k_B T/m}}$$

With oscillations

Separation factor $\alpha = \boxed{\frac{P_B}{P_A}}\sqrt{\frac{m_A}{m_B}}$

$P(u/c) \to P(c_A) \neq P(c_B)$

amplification factor $\gamma \equiv \frac{P_B}{P_A}$

P – passing probability

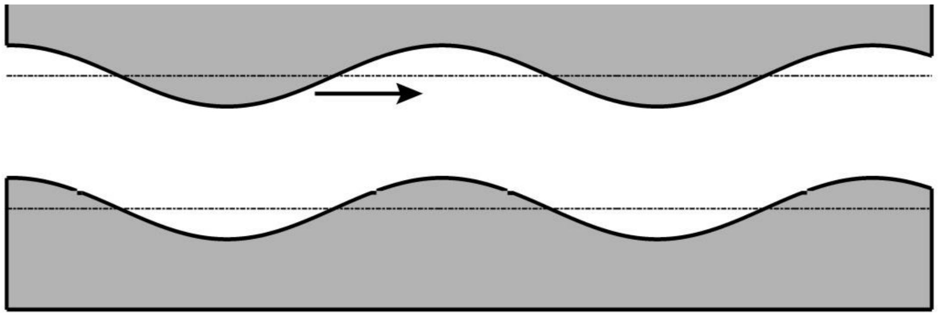
u – characteristic thermal speed

$c = \sqrt{2k_B T/m}$ – characteristic thermal speed of molecules

Numerical method

Molecular trajectory computations

1) Sample molecule at inlet
2) Calculate collision point
3) Calculate reflection from surface based on scattering law
4) Molecule escape though either exit surface

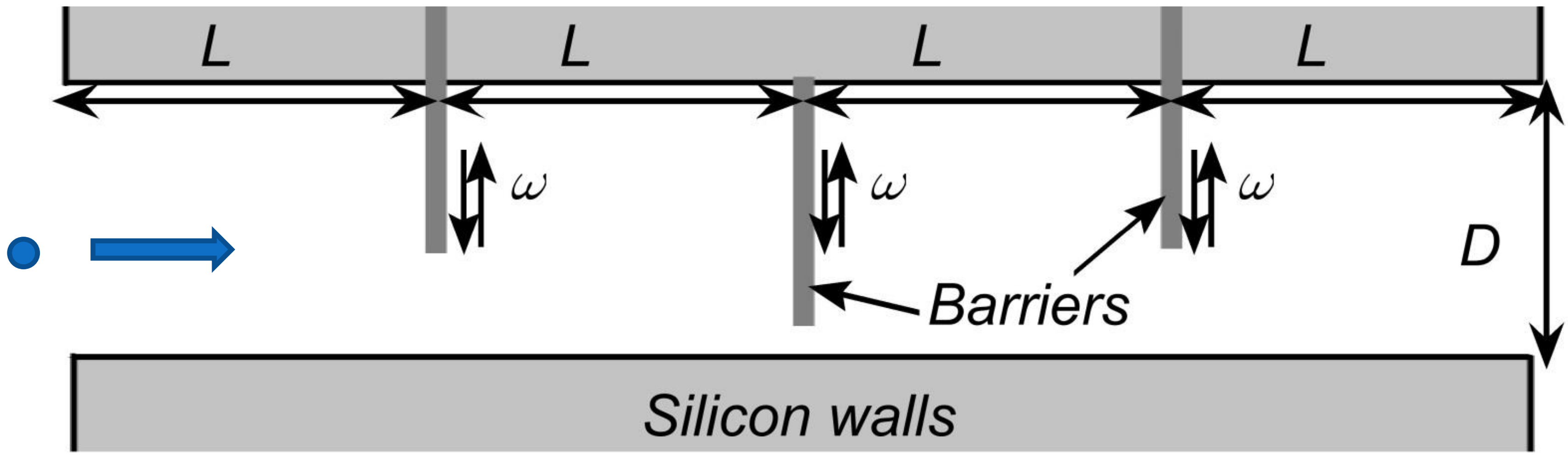


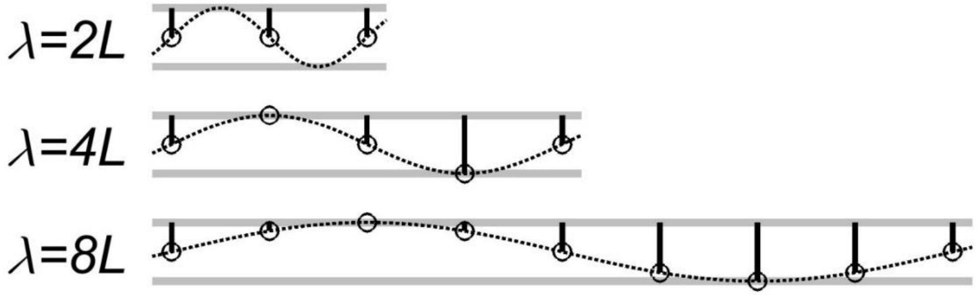
Target characteristic $P = N/N_{pas}$ – passing probability

$N = 10^7$ – number of probe molecules

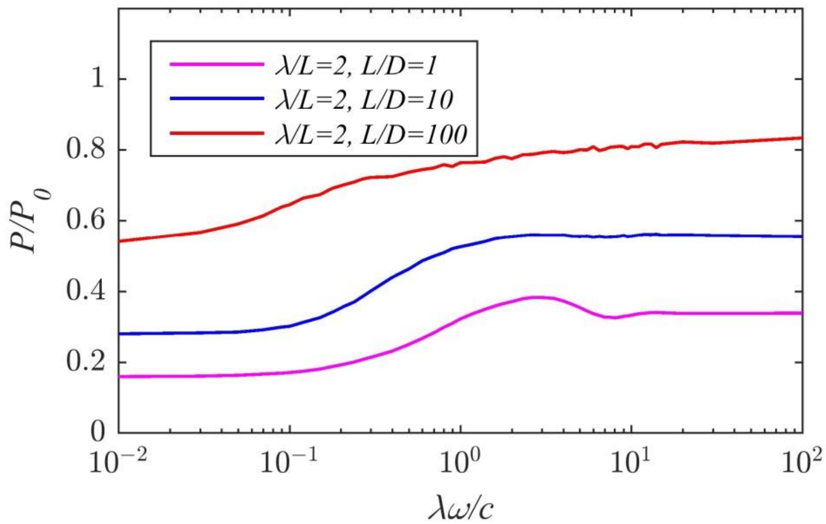
N_{pas} – number of molecules to pass through the channel

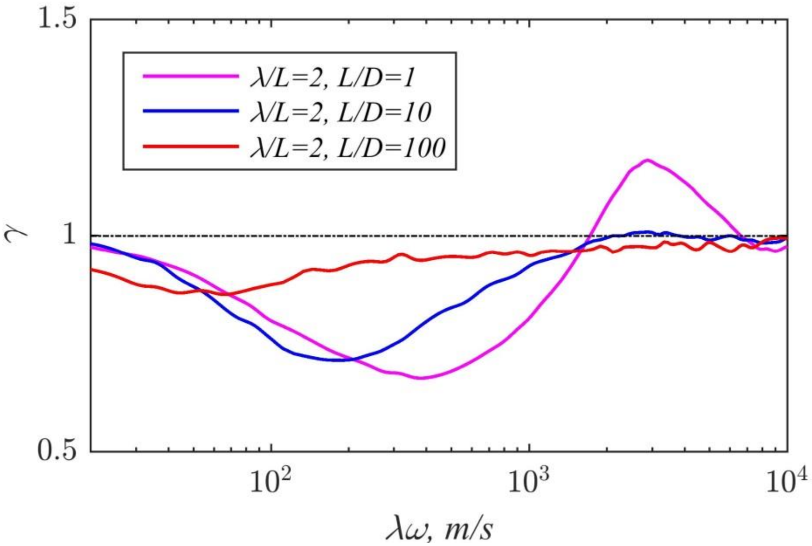
Problem №1. Channel with a series of barriers

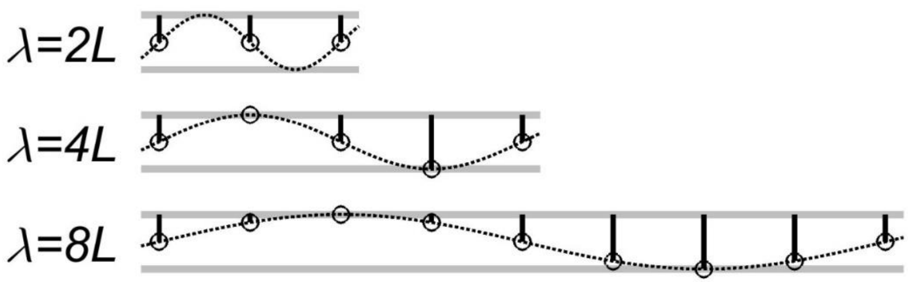




Influence of distance between barriers *L / D*

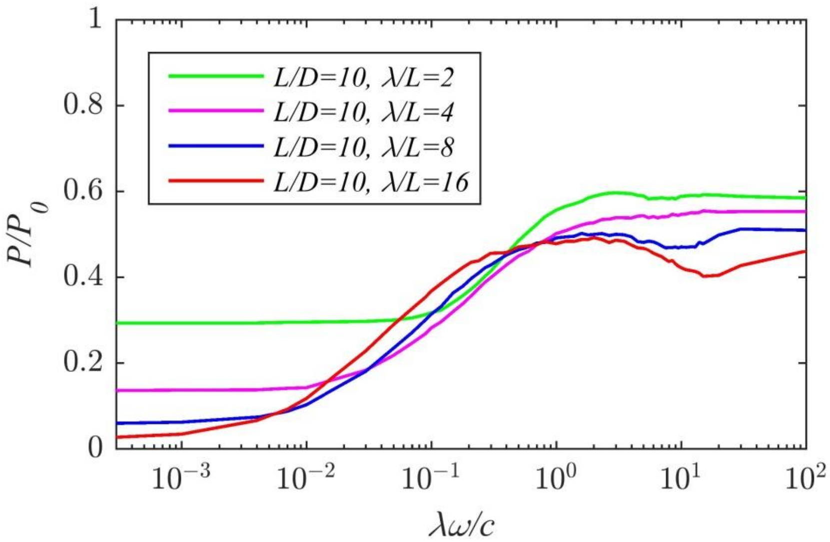


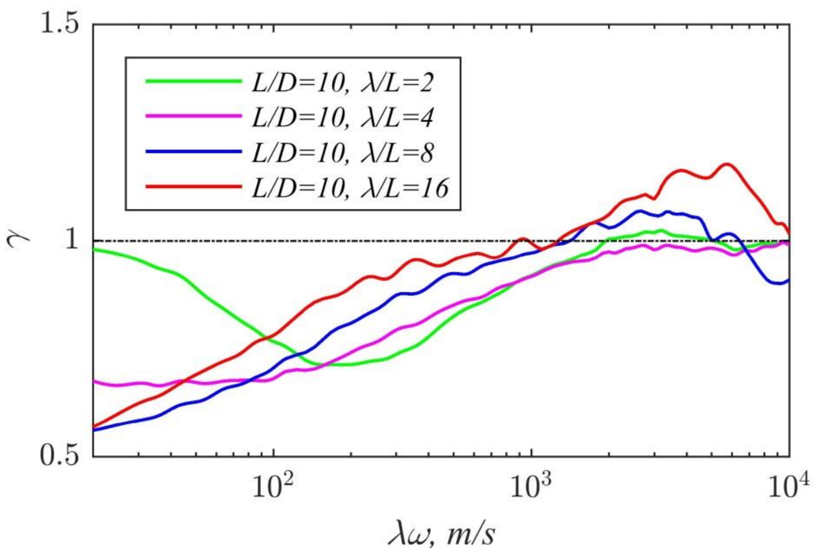


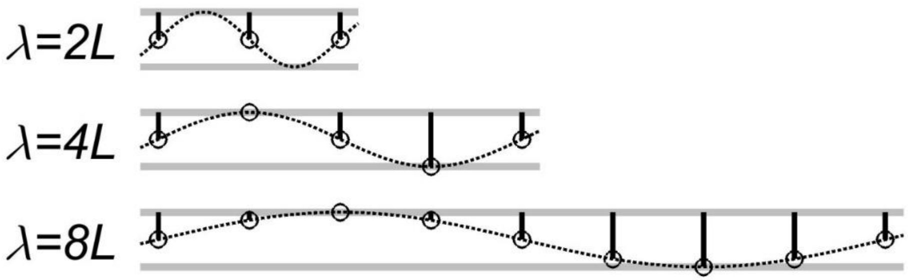


- Separation is observed when ratio of speeds $\lambda\omega/c$ reaches values around unity
- Effect vanishes for longer distances between barriers L/D
- Device with only 2 sections is used here

Influence of wave length λ

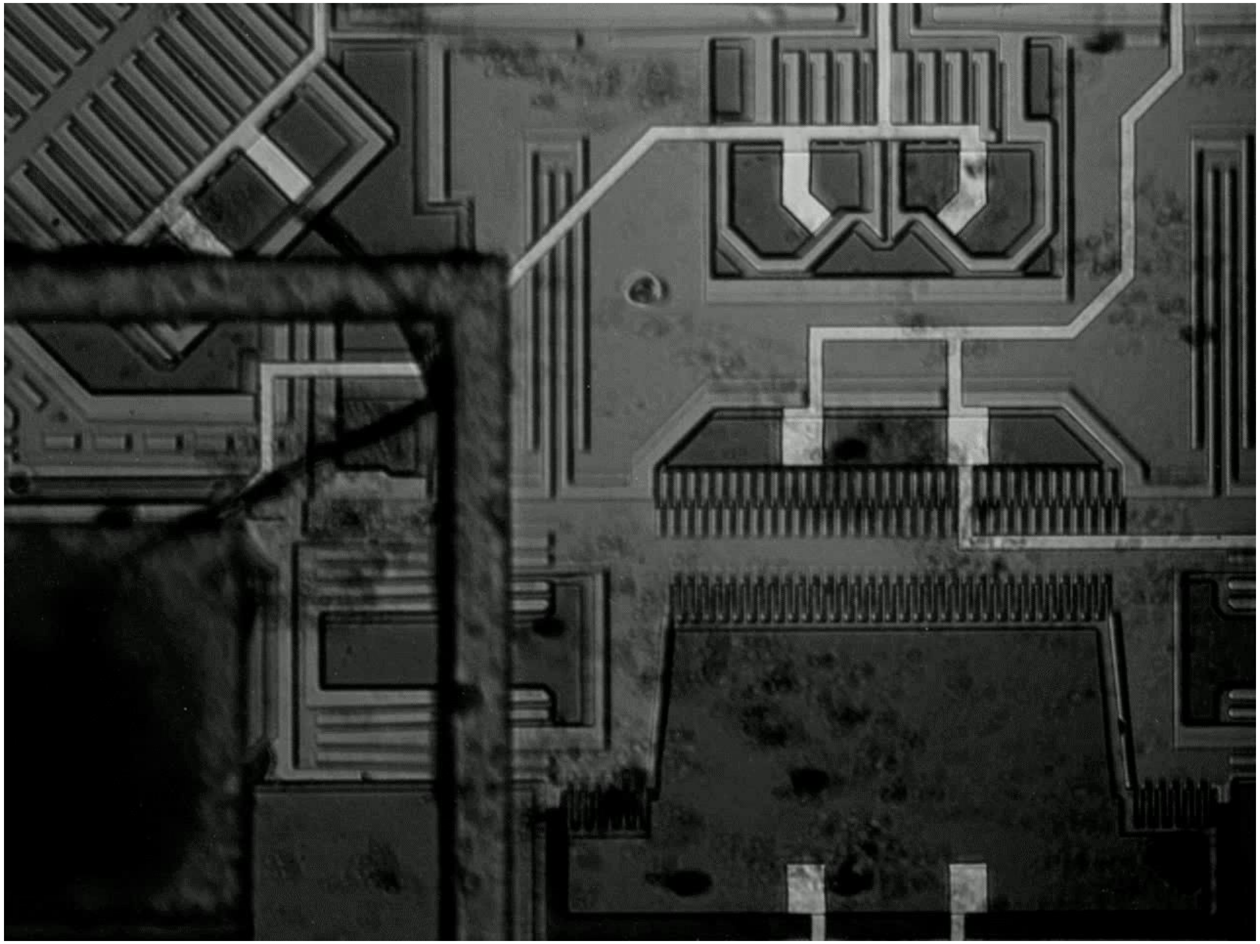






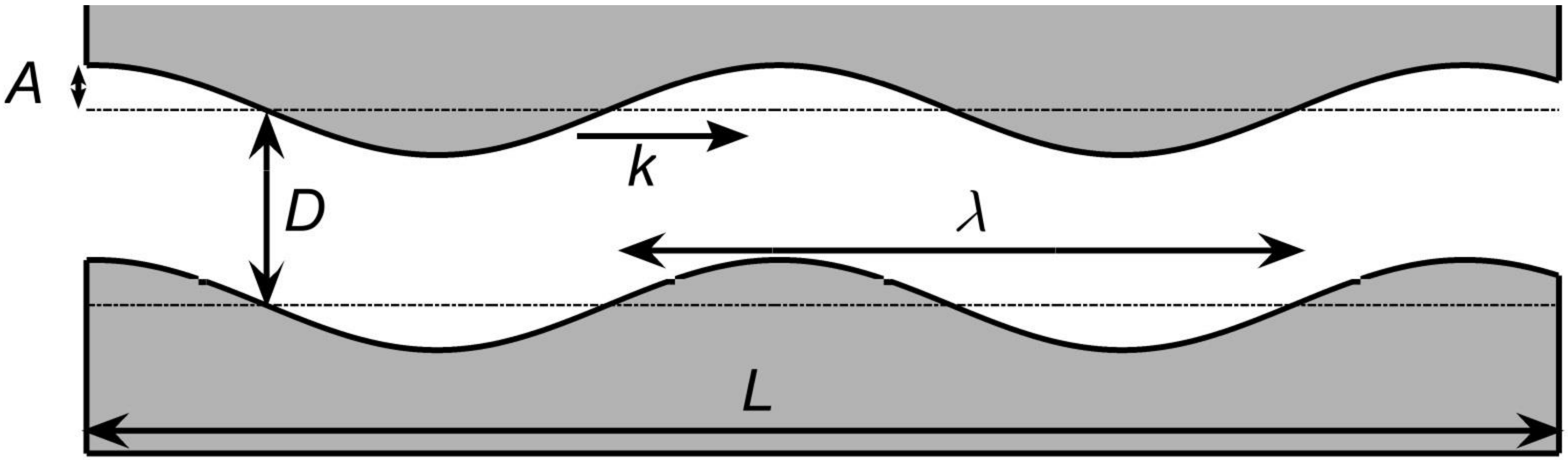
- By increasing number of sections and wave length one can achieve separation for higher values of L/D
- Reflection law and surface accommodation coefficients are important

Possible practical implementation

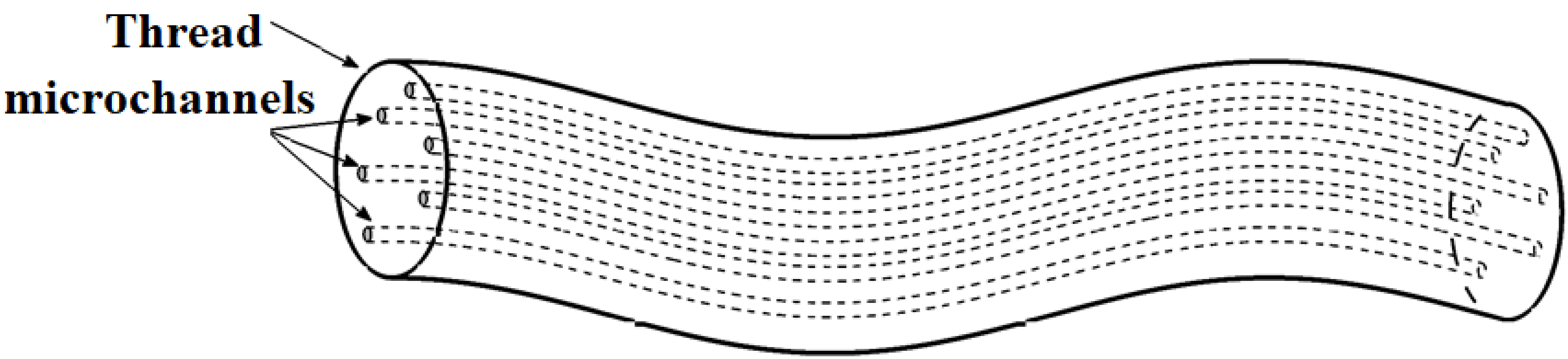


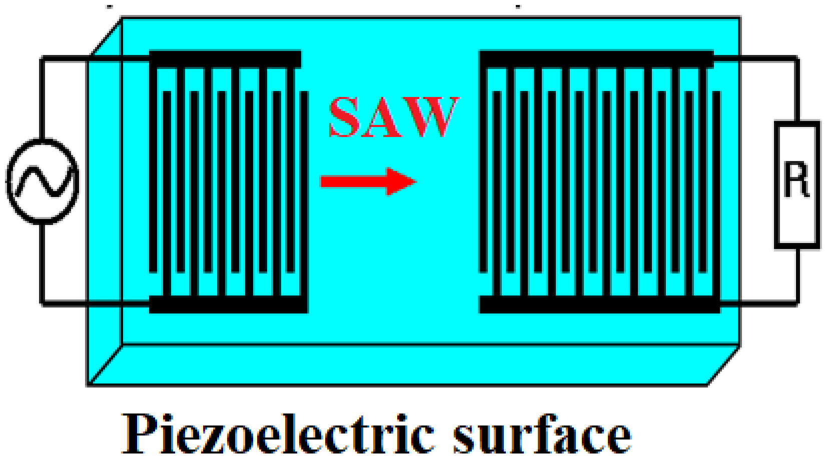
Video presented by laboratory of nano- and microsystem technology of St. Petersburgh polytechnic university

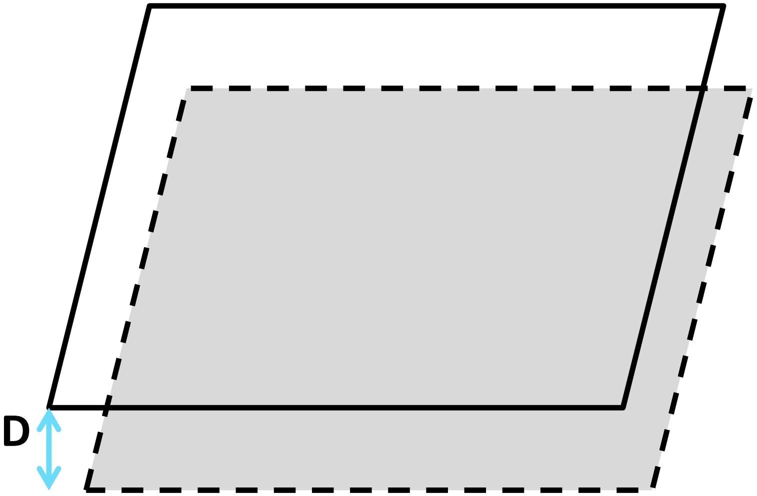
Problem №2. Curving channel



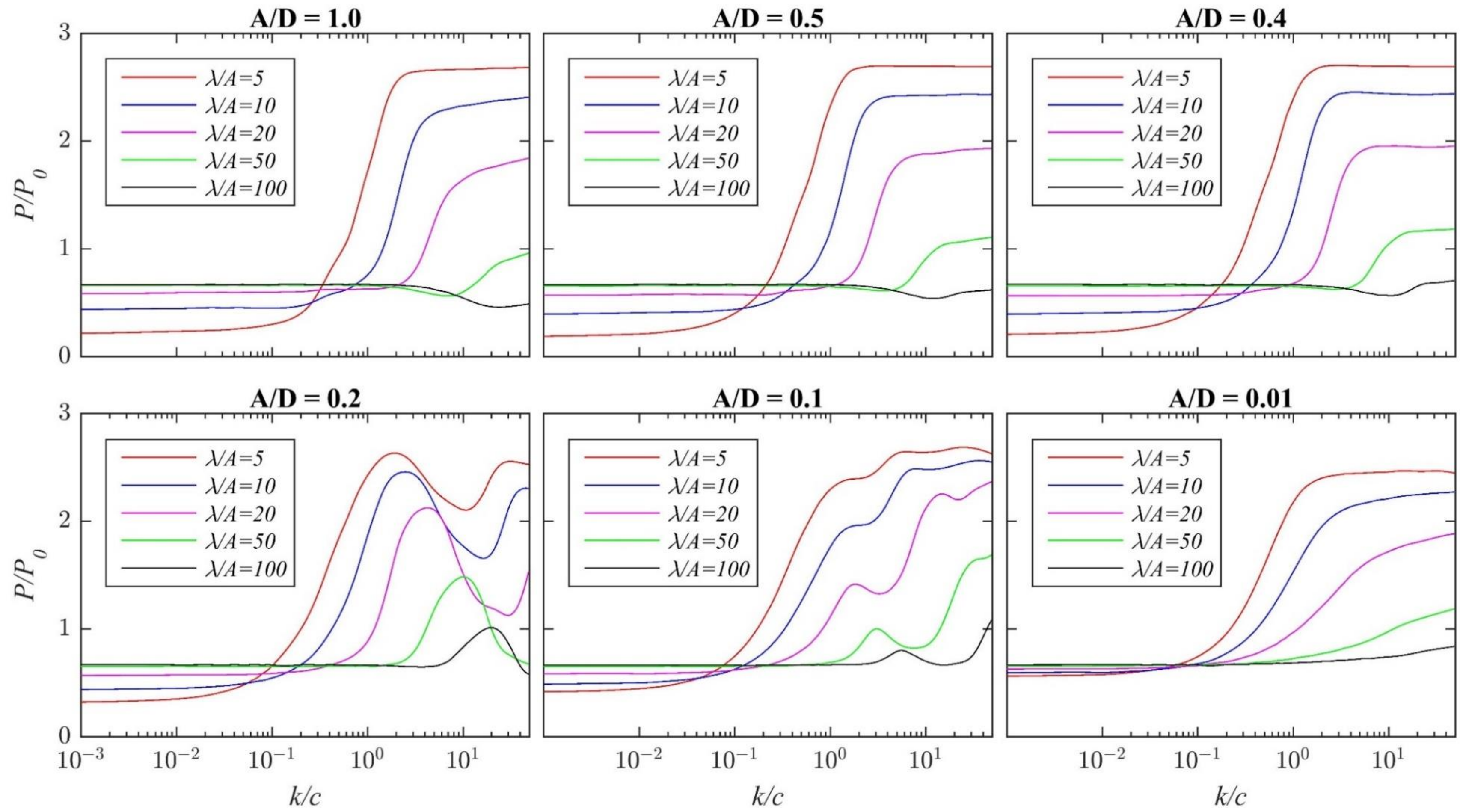
Possible practical implementations





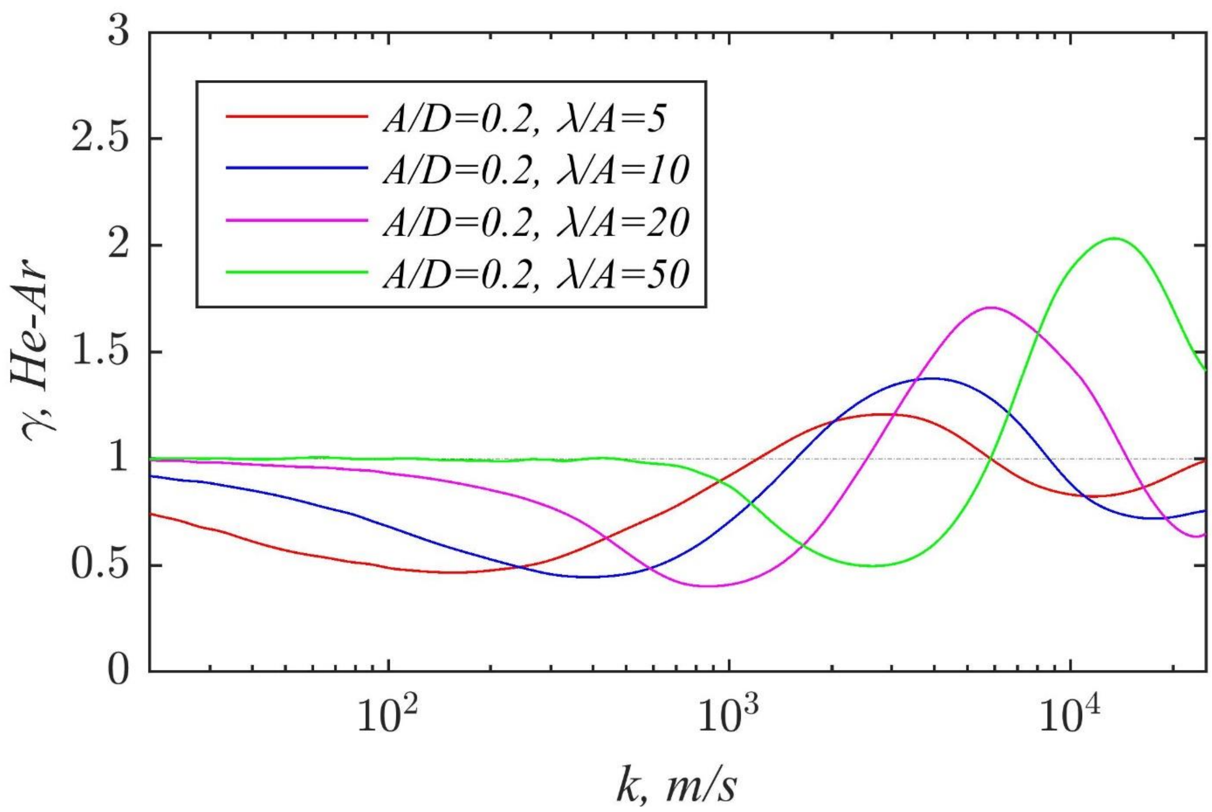


Influence of amplitude and wavelength



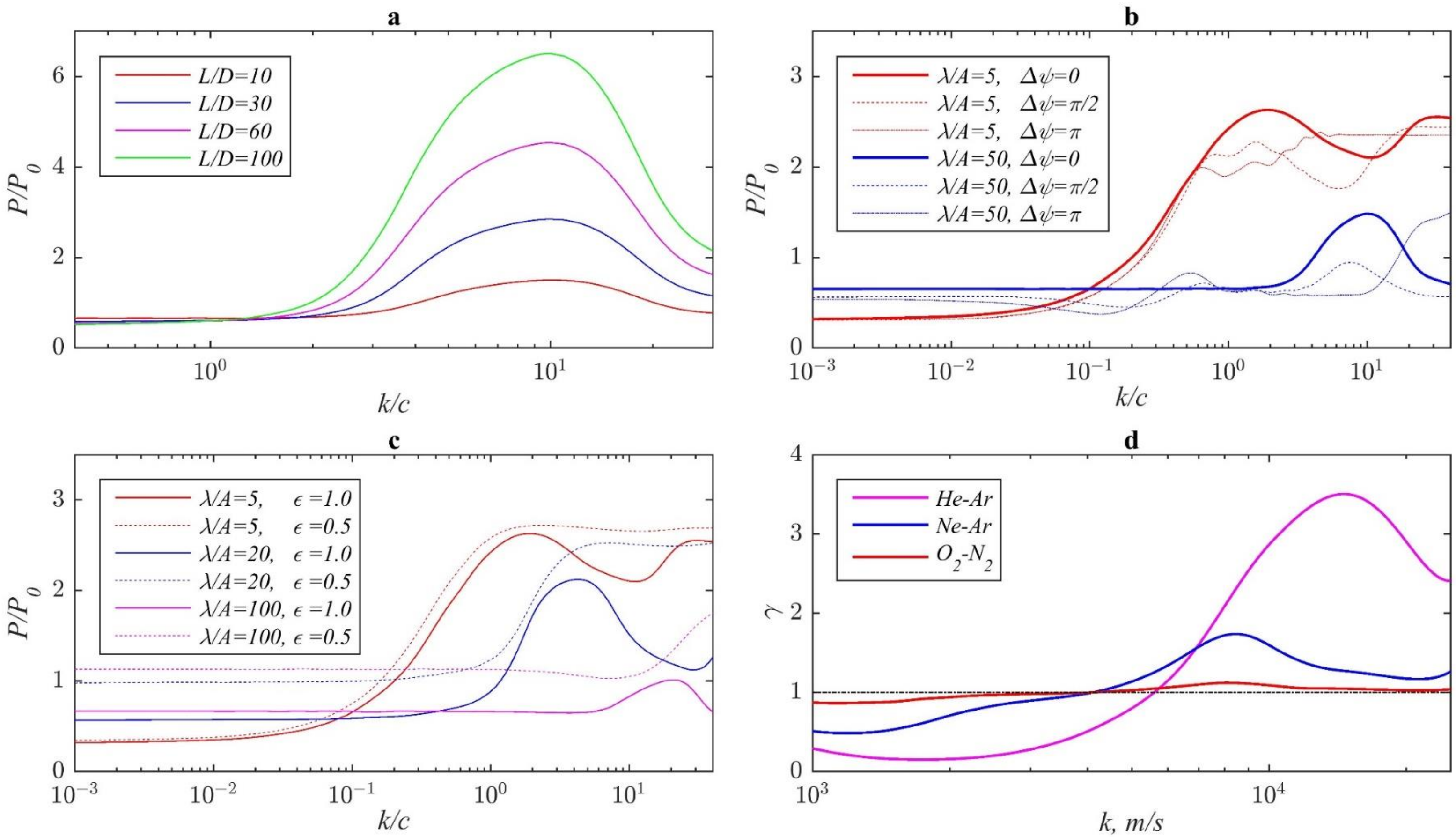
- Separation takes place in only narrow range of amplitudes A/D (~ 0.25)
- Effect is observed when ratio of speeds k/c reaches values around unity

Amplification factor γ for different wavelengths



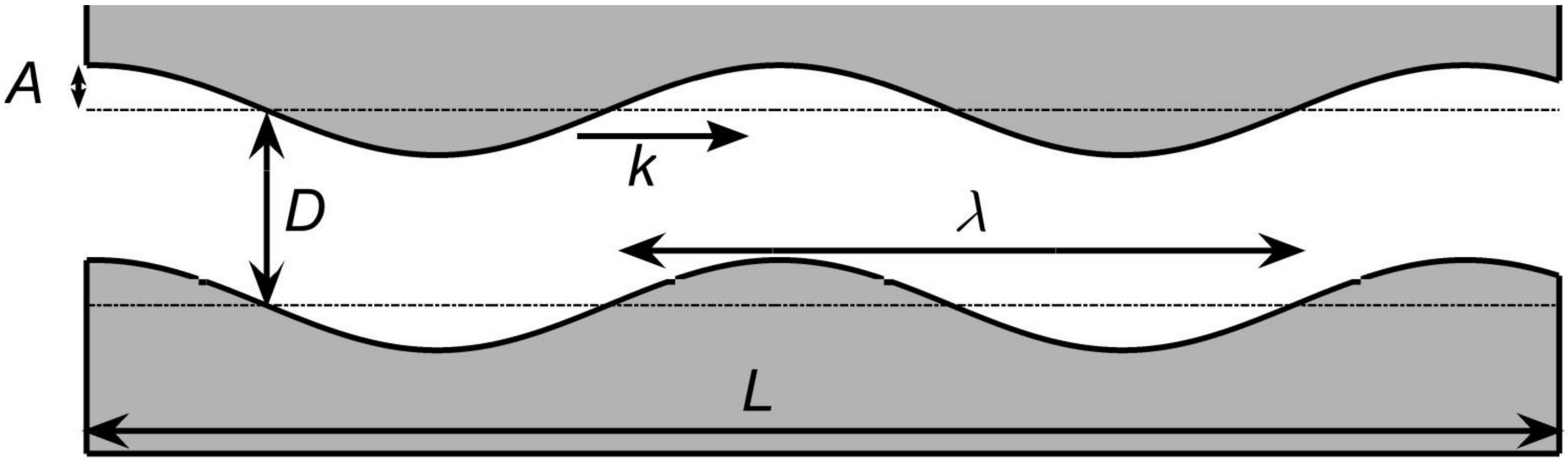
- Effect gets stronger for higher values of λ/A but requires higher values of surface wave speeds

Influence of other parameters

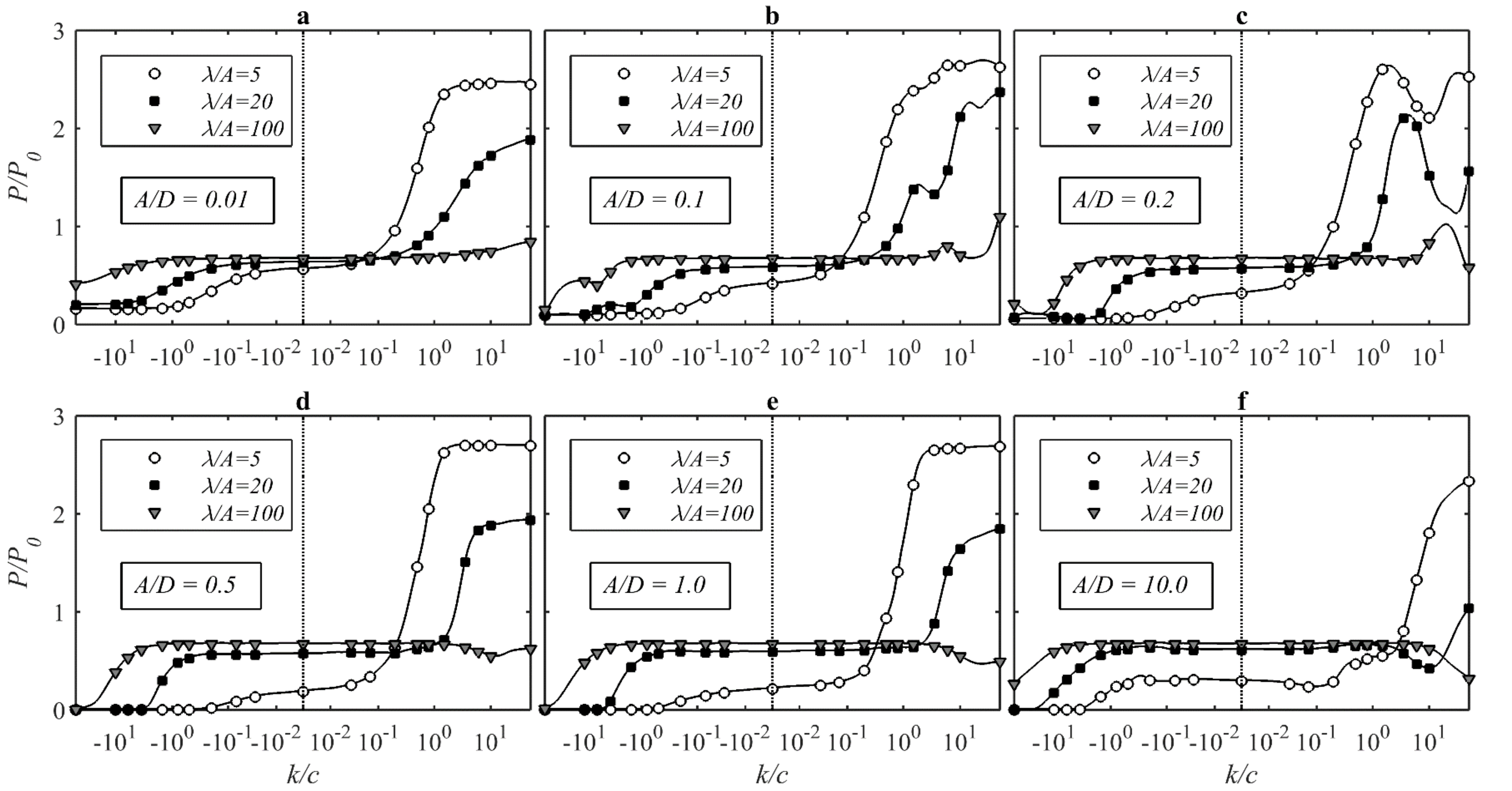


- Pumping gets stronger with increasing channel length L/D
- Separation is observed only for accommodation coefficient close to unity and when upper and lower surface move in same phase

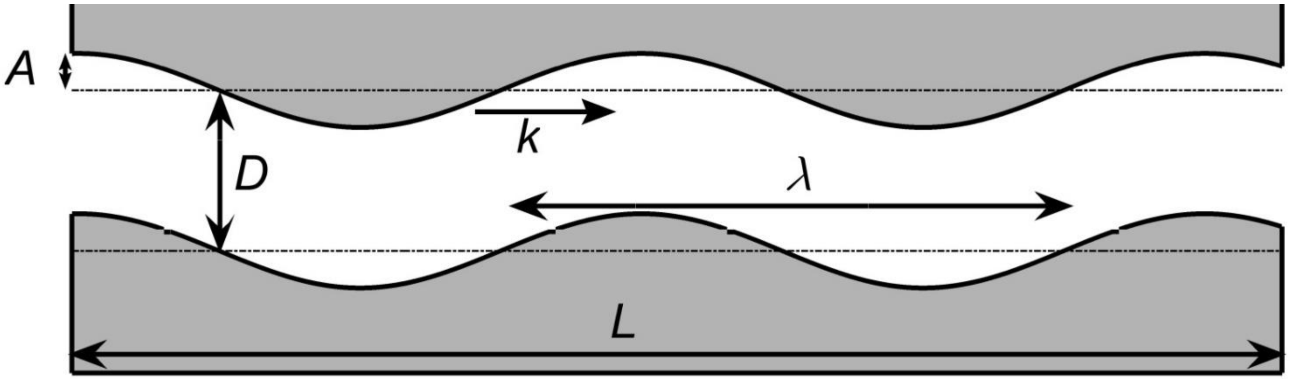
Extra. Gas pumping



Results for negative wavespeeds u/c



Gas pumping



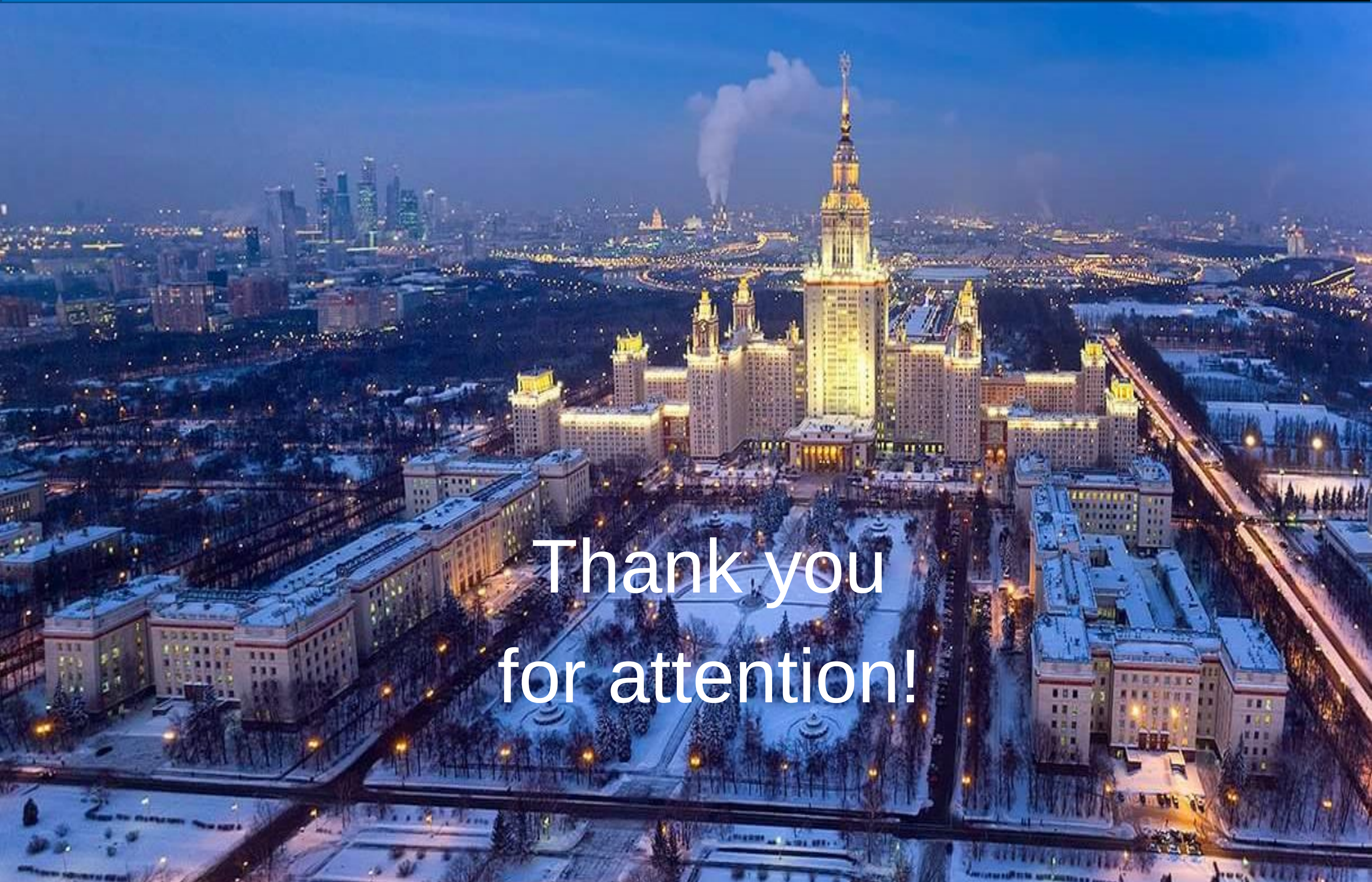
- Effect of pumping is observed in wide range of amplitudes A/D (from 0.01 to 10)
- Pumping gets stronger with increasing channel length L/D
- Effect gets weaker for higher values of λ/A
- Scattering law and values of accommodation coefficient are irrelevant
- Phase shift between upper and lower surface is irrelevant

Discussions

- High-frequency oscillations can significantly influence rarefied gas flow inside microstructures
- Influence is most noticeable when characteristic speed of surface motion becomes compatible with molecules thermal speed
- Presence of separation effect significantly depends on device parameters (surface conditions, amplitudes and frequencies of oscillations, geometry)
- When some characteristic oscillation speed is directed along channel axis one can get pumping effect

Future works:

- Computations at moderate Knudsen numbers are required
- Conduction physical experiments is also necessary


Thank you
for attention!