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«The electromagnetic wave amplification in thin superconducting film in non-linear mixed state»

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Problem statement

1. The electromagnetic wave interaction with the moving Abrikosov vortex lattice in type II superconductors can lead to amplification of electromagnetic waves. This requires very high velocities of Abrikosov vortex lattice in order to obtain electromagnetic waves amplification.

2. Let us show that amplification of an electromagnetic can be observed at velocities of the vortex structure that are less than the phase velocity of the waves.

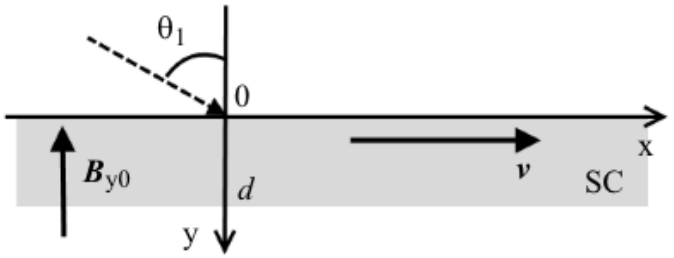

Figure 1. The geometry of the structure.
SC – thin superconducting film
B_{y0} - external magnetic field
d – thickness of superconducting film
v - velocity of Abrikosov vortex lattice

The behavior of the vortex structure is described by Larkin–Ovchinnikov model modified by Doettinger.
Transformation matrix for superconducting film: $\begin{pmatrix} 1 & 0 \\ A & 1 \end{pmatrix}$

$$A = \frac{d j_{z0}^{\,2}}{B_{y0}\ \left[1 \pm \left(1 - \frac{4\Phi_0^{\,2} j_{z0}^{\,2}}{\eta(0)^2 v^{*2}}\right)^{-1/2}\right]} \left[\frac{2\Phi_0}{\eta(0) v^{*2}} - \left(1 \pm \frac{4\Phi_0^{\,2} j_{z0}^{\,2}}{\eta(0)^2 v^{*2}}\right)^{1/2} \frac{k_x}{\omega j_{z0}}\right],$$

j_{z0} - current density
$\eta(0)$ - viscosity coefficient
k_x - projection of wave vector onto Ox
v^* - the instability velocity

Results :
reflection coefficient R calculation

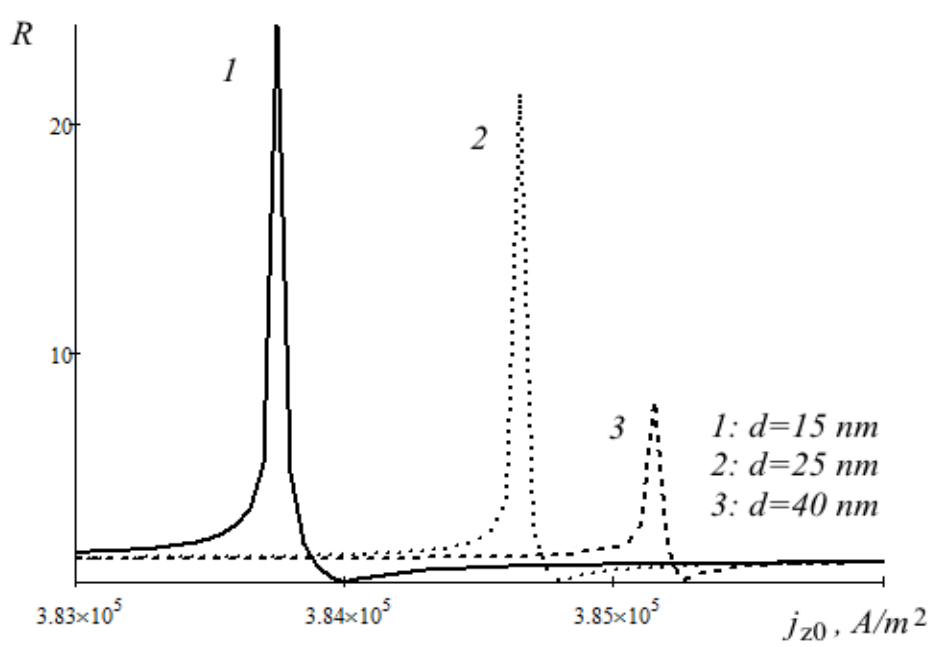

Figure 2. R for forward wave.
Structure: thin superconducting film MgO on substrate $SrTiO_2$. The thickness of substrate is 8 μm, B_{y0}=1 T, angle of incidence θ_1=0.5, $v^* = 1000\ m/s$, $\eta(0) = 1 \cdot 10^{-6}\ N \cdot s/m$

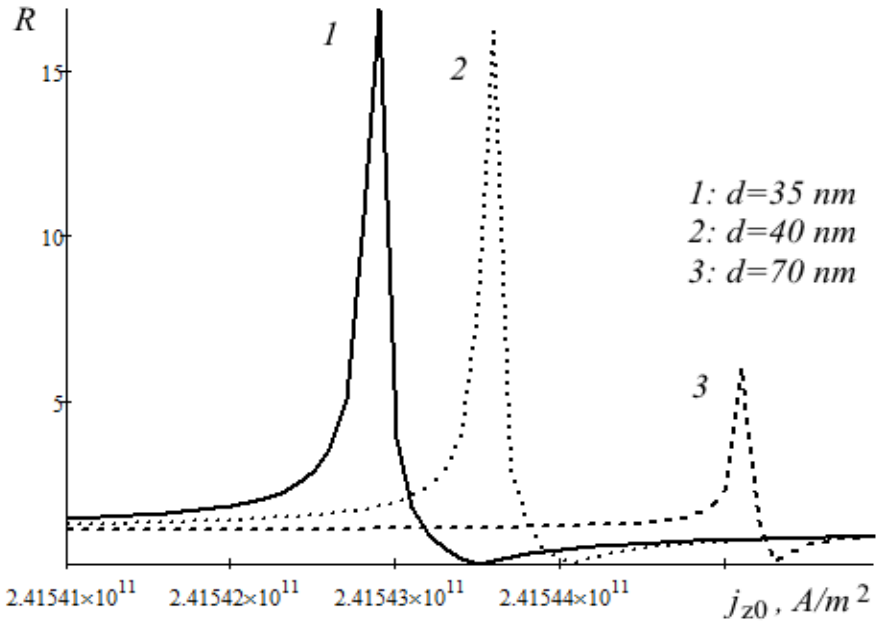

Figure 3. R for backward wave.
Structure: thin superconducting film MgO on substrate $SrTiO_2$. The thickness of substrate is 8 μm, B_{y0}=1 T, angle of incidence θ_1=0.5, $v^* = 1000\ m/s$, $\eta(0) = 1 \cdot 10^{-6}\ N \cdot s/m$

Conclusions

1. The electromagnetic wave can demonstrate amplification due to the energy of the Abrikosov vortex lattice.
2. This amplification is observed at low velocities of the vortex structure $\sim 1\ km/s$.
3. The structure demonstrated non-reciprocal character.
4. For forward wave (the direction of electromagnetic wave propagation coincides with the direction of vortex motion in a superconductor), we can observe the amplification at small values of the transport current density $\sim 3.8 \cdot 10^5\ A/m^2$.
5. The results obtained in this work can be used to create superconducting amplifiers and switches for the terahertz and optical ranges.

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