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Ultrasound as Functional Influence Tool on FeB Pair Association in Silicon Solar Cells

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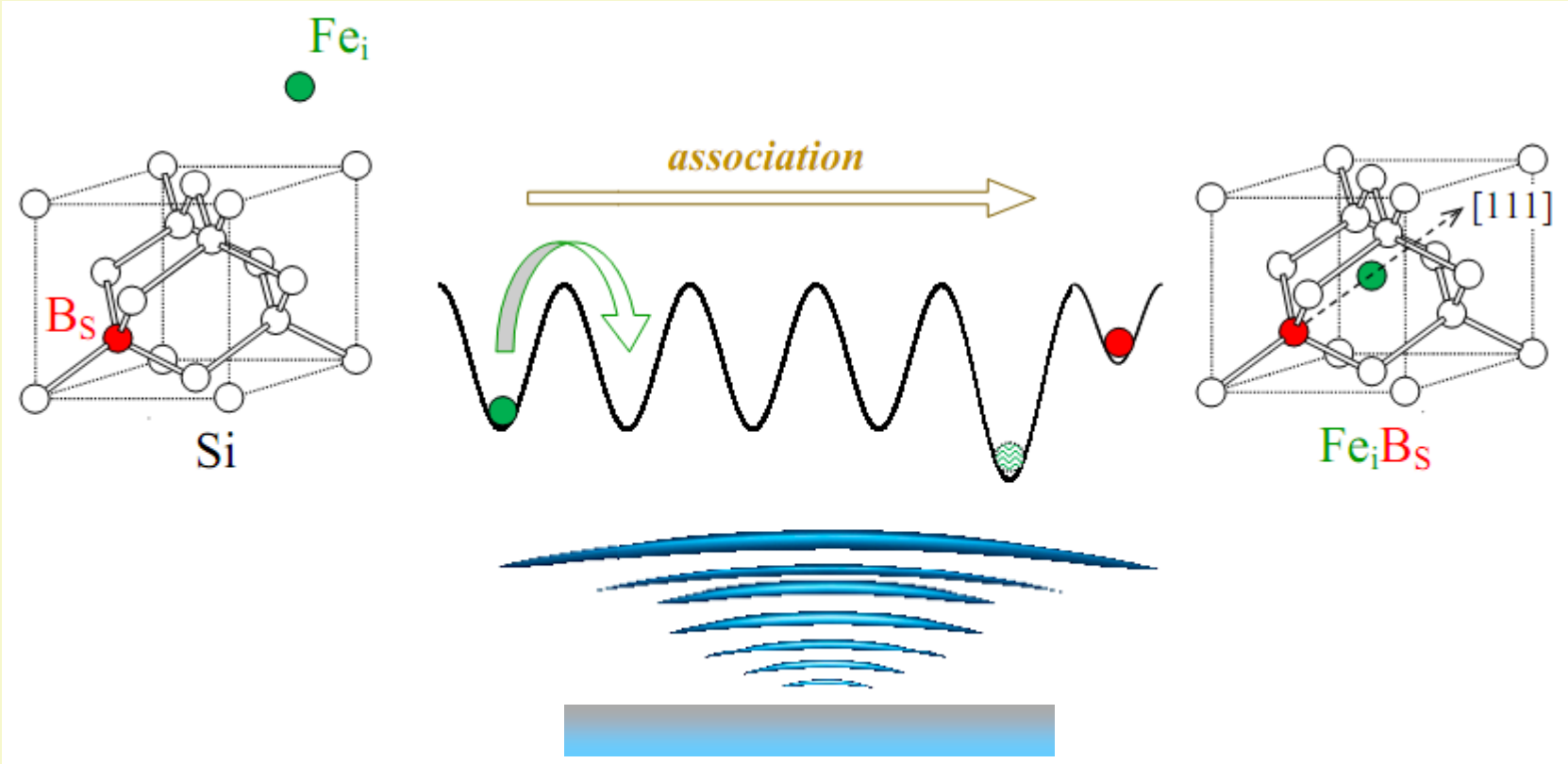
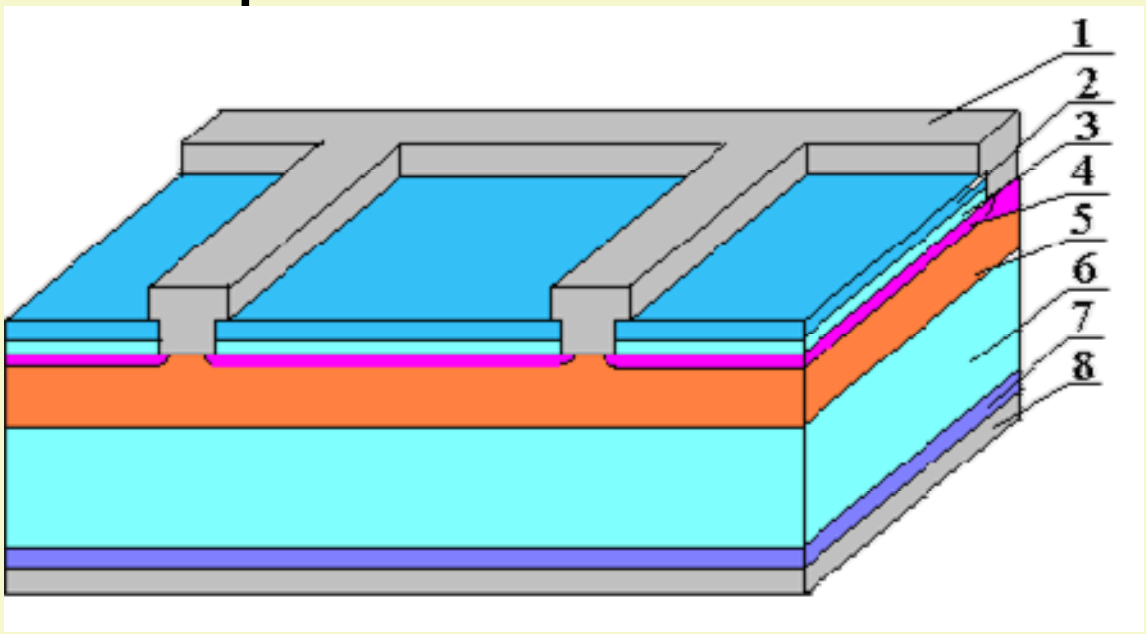
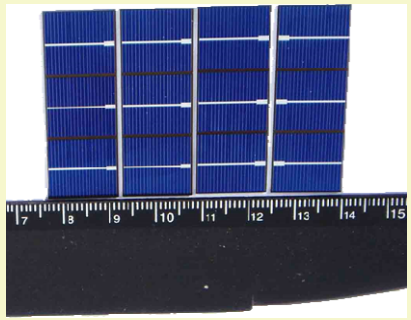
Main goal:

to investigate experimentally the FeB pair association in silicon solar cells under ultrasound loading conditions

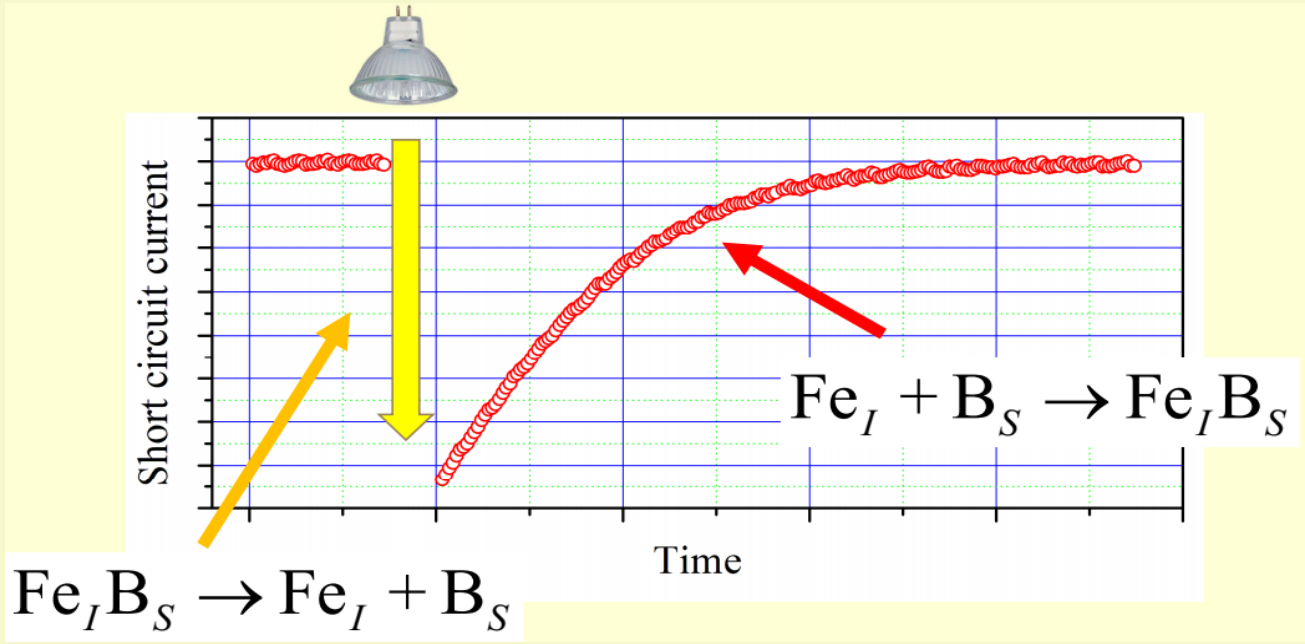


Samples:

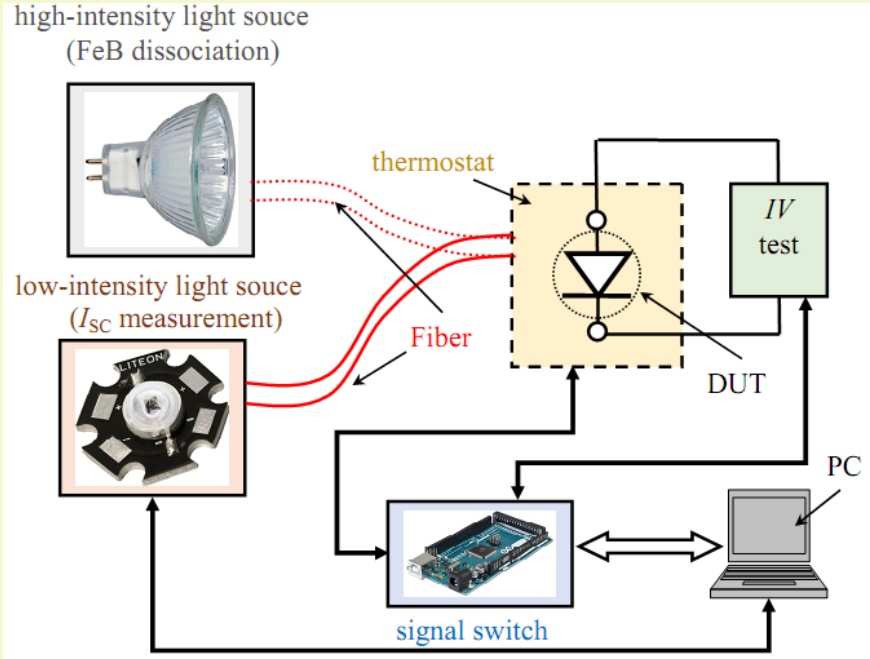




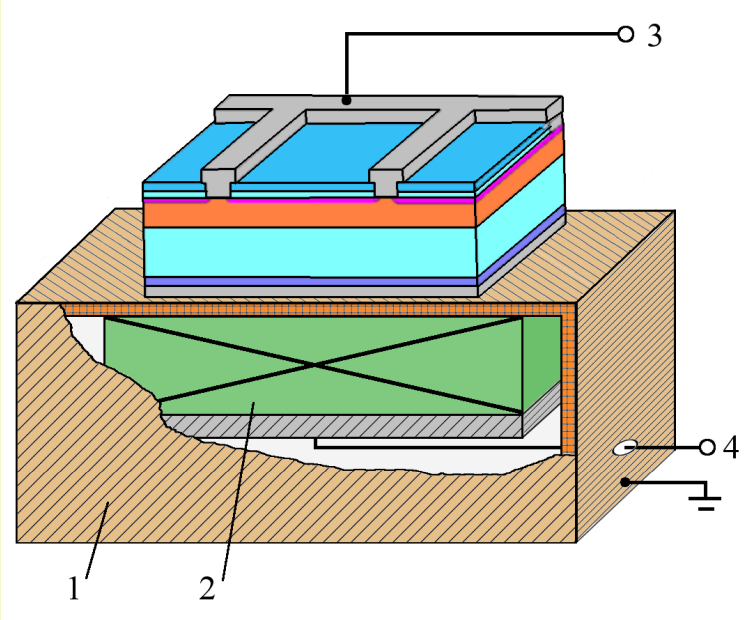
1 - front metal electrode (Al);
2 - Si_3N_4 (40 nm);
3 - SiO_2 (30 nm);
4 - induced n++ - layer;
5 - diffusion n+ - layer (0.7 μm);
6 - base region (p-Si:B, 10 Ω·cm, 380 μm);
7 - diffusion p+ -layer (0.6 μm);
8 - rear metallization (Al)



Experimental setup:



Ultrasound loading (USL)



1 – Cu foil
2 – piezoelectric transducer
3 – contacts for IV measuring
4 – contacts for US excitation

1) longitudinal wave (thickness vibrations)

$f_{US} = 2.4; 4.1; 5.4; 9.0; 14; 18; 31$ MHz

2) transverse wave (radial vibrations)

$f_{US} = 0.3$ MHz

ultrasound intensity $W_{US} \leq 0.6$ W/cm^2

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$$I_{SC} = \frac{W_{ph}(1-R)q\beta\lambda}{hc}\,\frac{\alpha\sqrt{D\tau}}{1+\alpha\sqrt{D\tau}}$$

$$\tau^{-1} = \tau_{rad}^{-1} + \tau_{Aug}^{-1} + (\tau_{SRH}^{Fe_i})^{-1} + (\tau_{SRH}^{FeB})^{-1} + \tau_{other}^{-1}$$

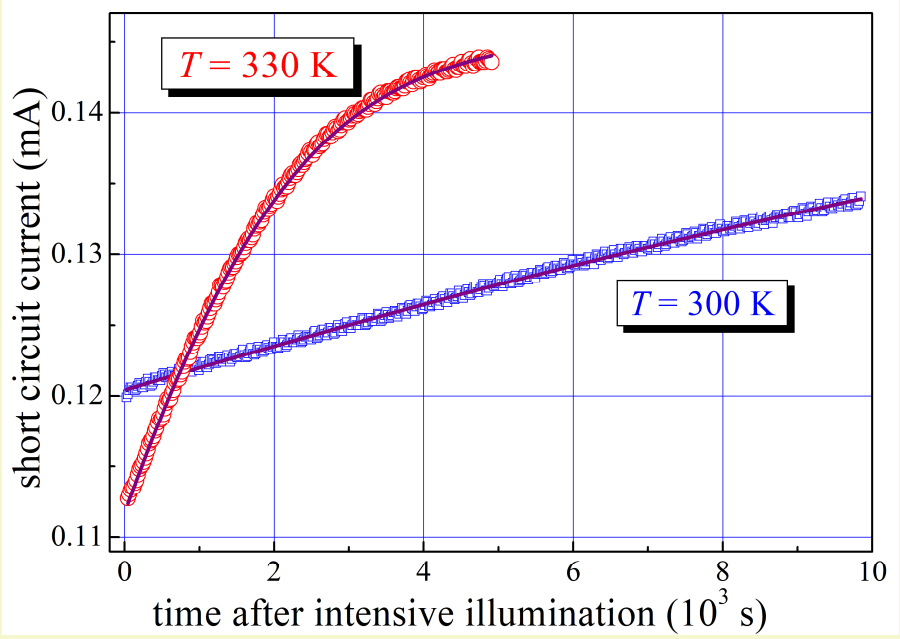
$$N_{Fe}(t) = (N_{Fe,0} - N_{Fe,eq})\exp\left(-\frac{t}{\tau_{ass}}\right) + N_{Fe,eq}$$

$$\tau_{SRH}^{Fe_i,FeB} = \frac{\tau_{p0}(n_0 + n_1) + \tau_{n0}(N_A + p_1)}{N_A + n_0}$$

$$N_{Fe,eq} = \frac{N_{Fe,0}}{\left[1 + N_A 10^{-23}\exp\left(\frac{0.582}{kT}\right)\right]\left[1 + \exp\left(\frac{E_F + 0.394}{kT}\right)\right]}$$

$$\tau_{n0,p0} = (N_{trap}\sigma_{n,p}\upsilon_{th,n,p})^{-1}$$

○ calculated values ○ experiment parameters



○ extracted parameters

points – experiment,
lines - fitting

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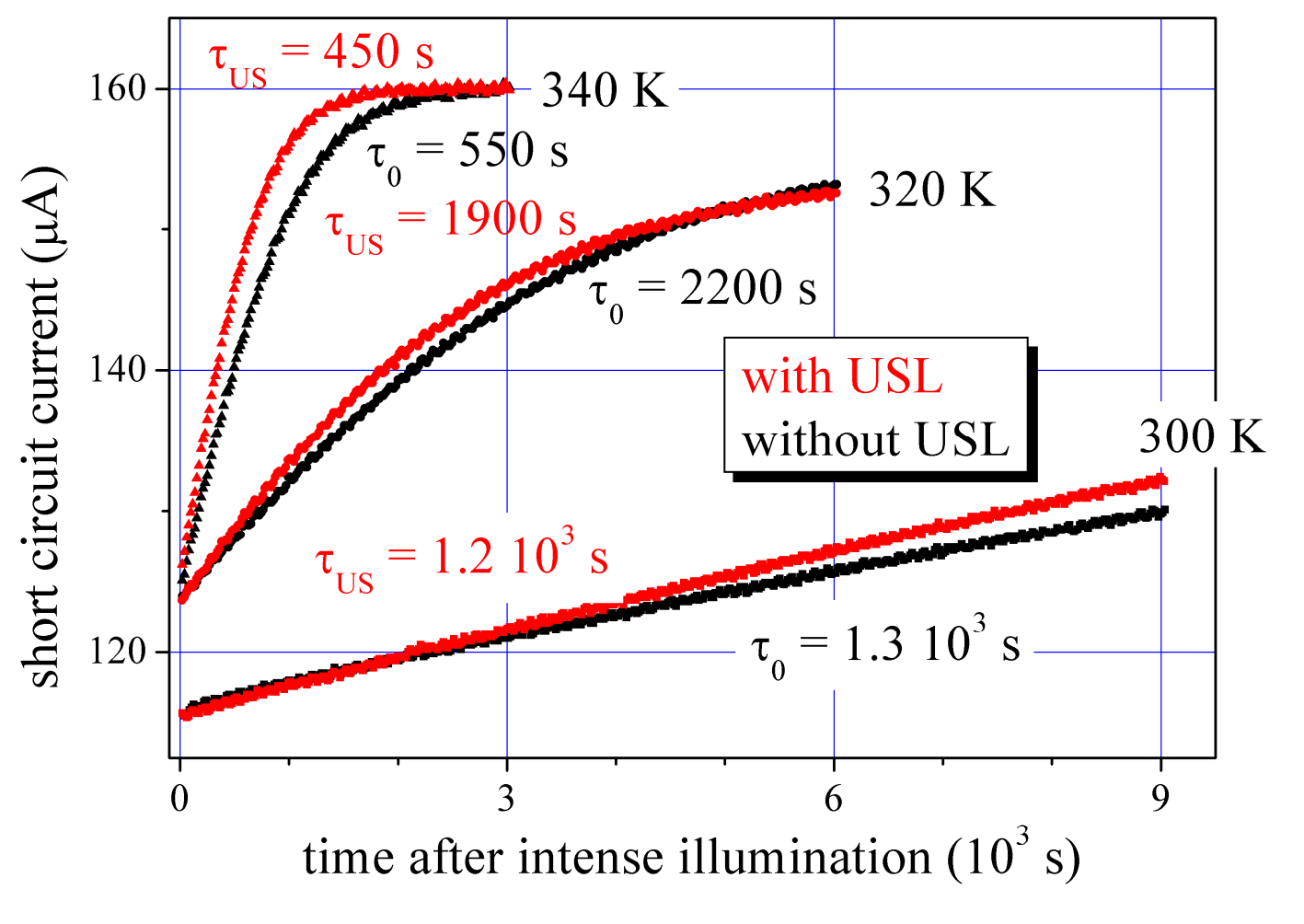
Results



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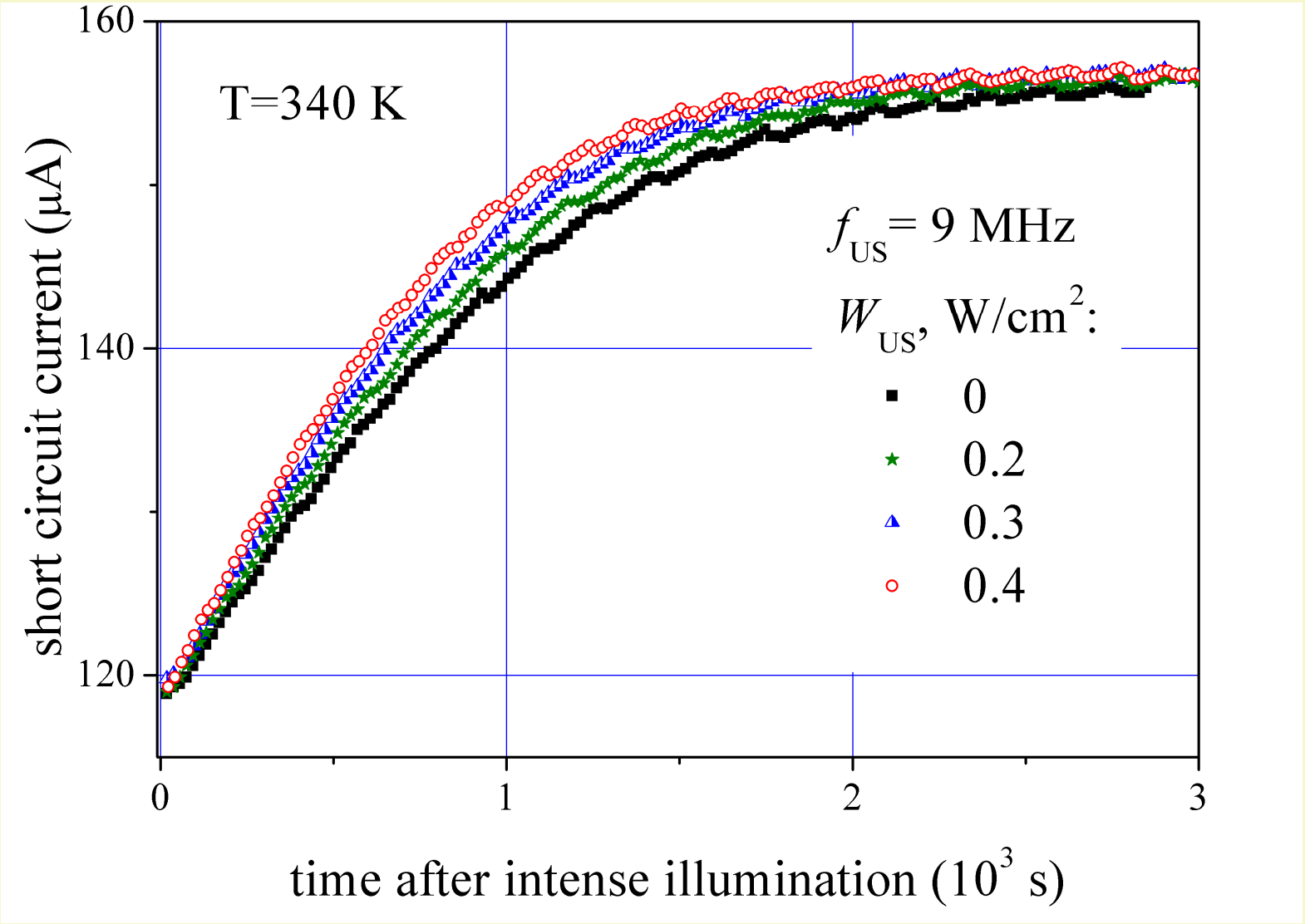
Results



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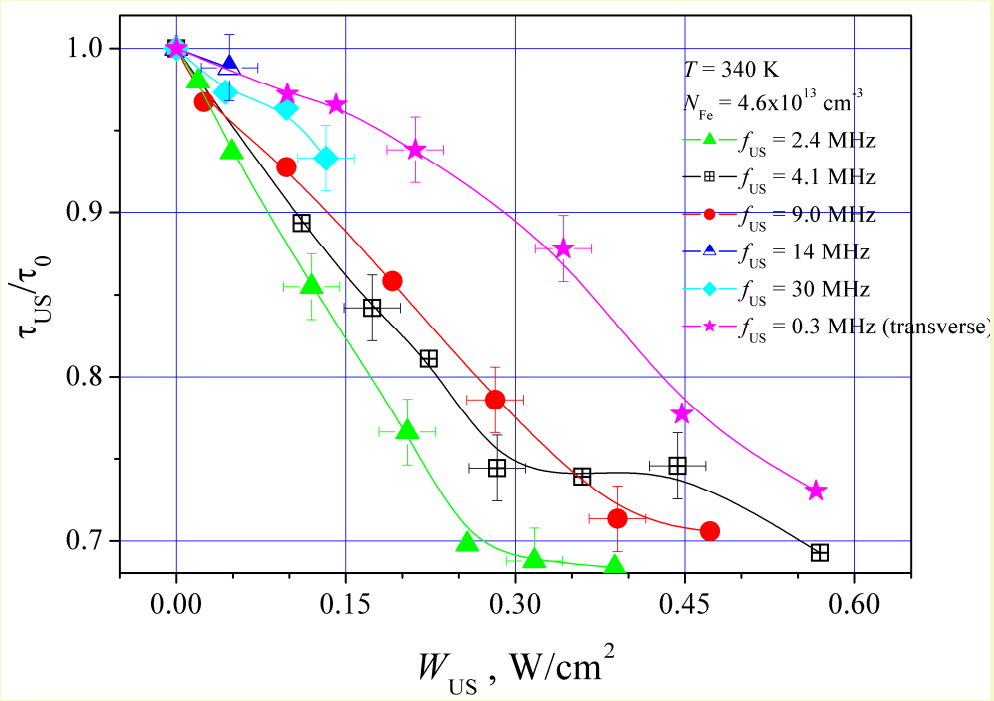
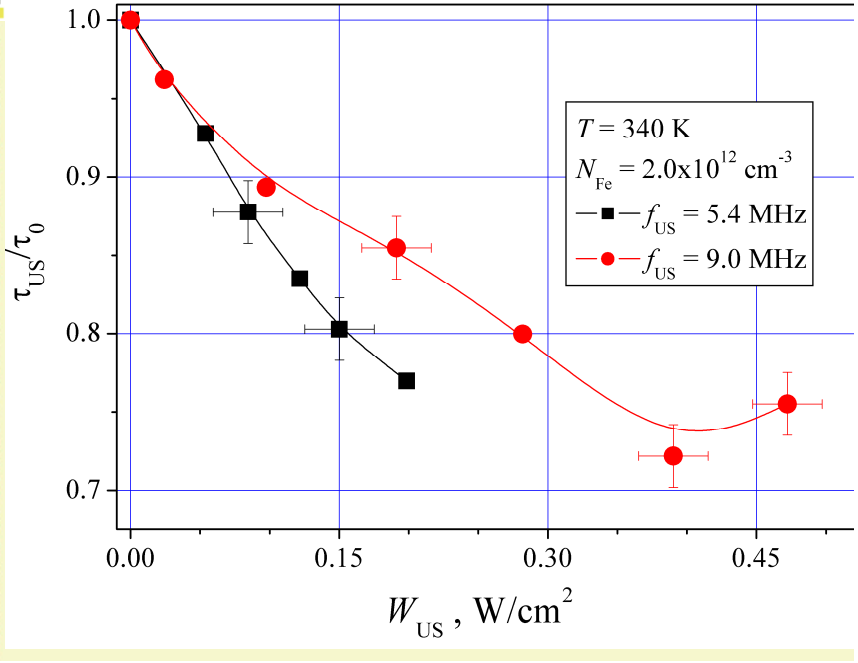
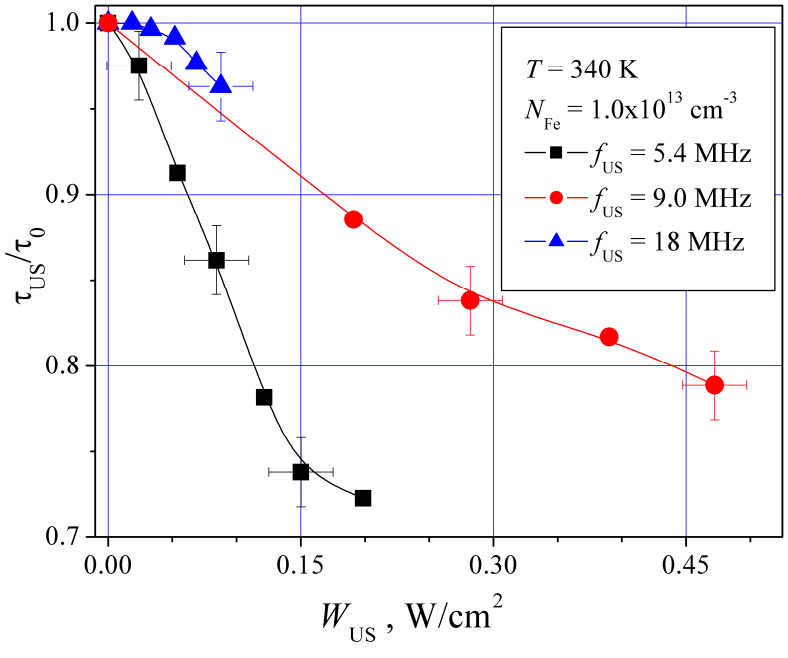
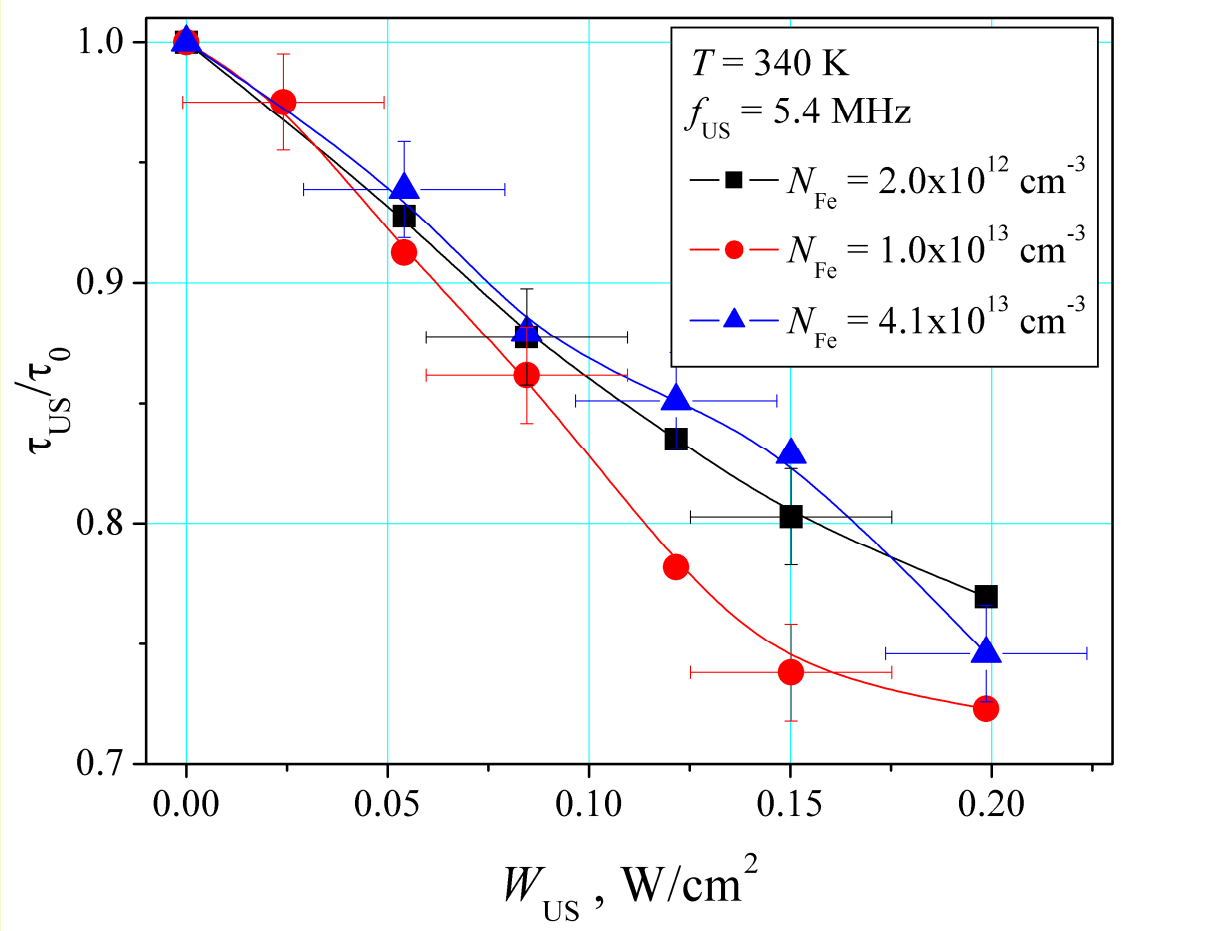
Results



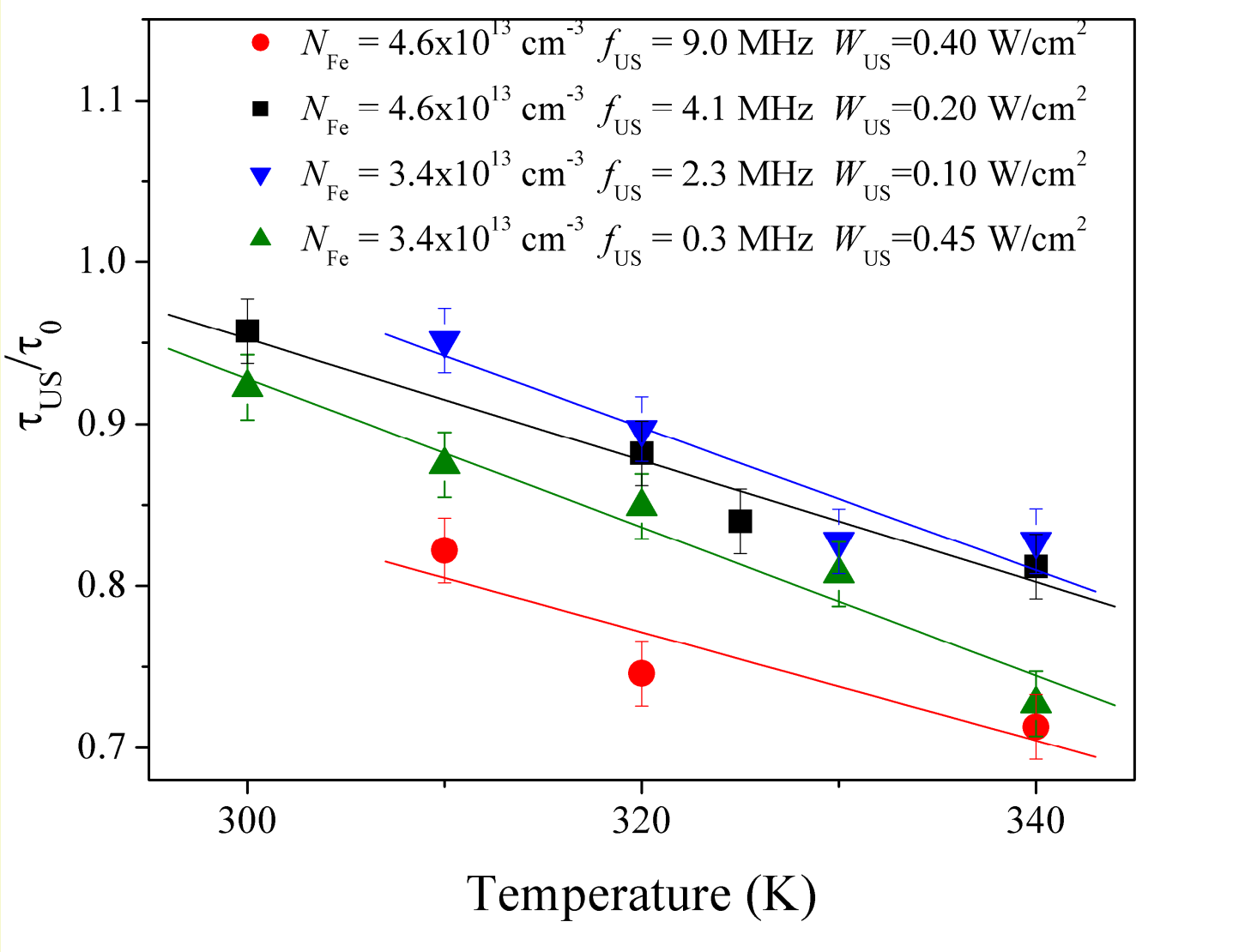




Results


T = 340 K
f_US = 5.4 MHz
N_Fe = 2.0x10^12 cm^-3
N_Fe = 1.0x10^13 cm^-3
N_Fe = 4.1x10^13 cm^-3
τ_US/τ_0
W_US , W/cm^2
1.0
0.9
0.8
0.7
0.00
0.05
0.10
0.15
0.20

Results


N_{Fe} = 4.6x10^{13} cm^{-3} f_{US} = 9.0 MHz W_{US}=0.40 W/cm^2
N_{Fe} = 4.6x10^{13} cm^{-3} f_{US} = 4.1 MHz W_{US}=0.20 W/cm^2
N_{Fe} = 3.4x10^{13} cm^{-3} f_{US} = 2.3 MHz W_{US}=0.10 W/cm^2
N_{Fe} = 3.4x10^{13} cm^{-3} f_{US} = 0.3 MHz W_{US}=0.45 W/cm^2
τ_{US}/τ_0
1.1
1.0
0.9
0.8
0.7
300
320
340
Temperature (K)

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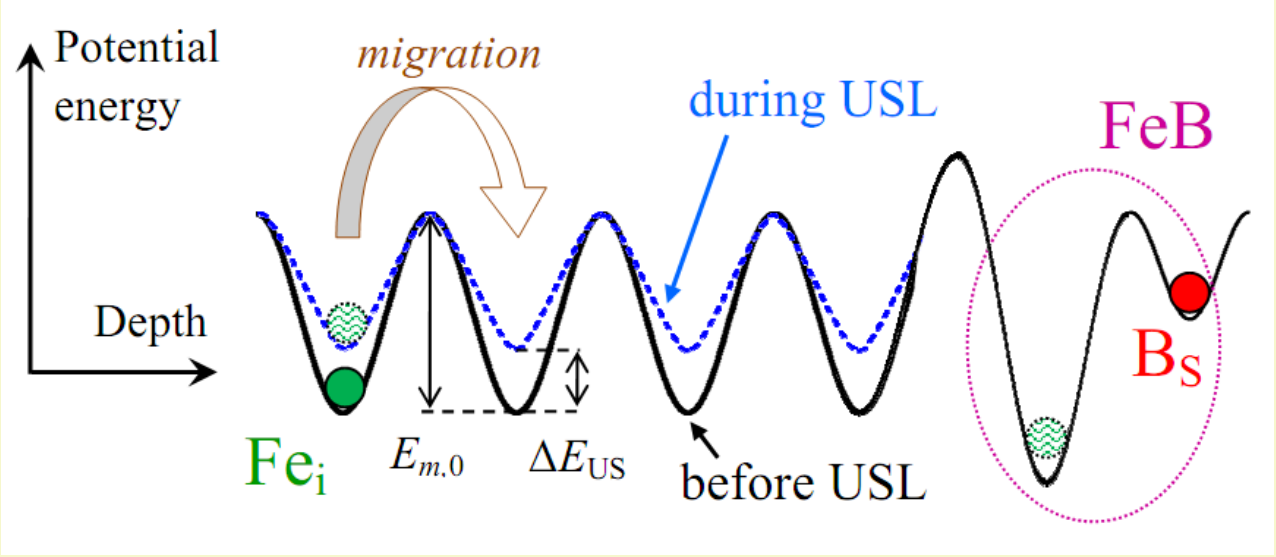
Discussion

$$\tau_{ass} = \frac{\varepsilon\varepsilon_0 k_B T}{q^2 D_{Fe} N_A} = \frac{\varepsilon\varepsilon_0 k_B T}{q^2 D_{0,Fe} N_A} \exp\left(\frac{E_{m,\mathrm{Fe_i}}}{k_B T}\right)$$

iron atom migration energy

$$E_{m,\mathrm{Fe_i}} \xrightarrow{\text{ultrasound}} E_{m,\mathrm{Fe_i}} - \Delta E_{\mathrm{US}}(T, W_{\mathrm{US}}, f_{\mathrm{US}})$$

$$\Delta E_{\mathrm{US}} \le 10 \text{ meV}$$



CONCLUSION

- ✓ The effect of the acoustically induced acceleration of FeB pairing in silicon solar cell has revealed
- ✓ The efficiency of ultrasound influence decreases with the acoustic waves frequency rising and the temperature drop and does not depend on iron concentration. The effect saturation with ultrasound intensity increase is observed
- ✓ The analysis has shown that these effects are caused by the acoustically induced decrease in the migration energy of iron atom

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