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THE DISLOCATION-ENHANCED SNOEK EFFECT - DESE IN IRON

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Abstract - The dislocation-enhanced Snoek effect - DESE in nitrogen doped iron is reported. The nitrogen DESE shows similar properties as already reported carbon DESE in iron. Thermal instability of the DESE in iron is clearly shown. A general discussion on the DESE in bcc metals is given.

I - INTRODUCTION

The dislocation-enhanced Snoek effect - DESE has been recently observed in deformed high purity bcc metals containing controlled concentration of foreign /heavy/ interstitial atoms - FIA's /C,N,O/ . This effect occurs at nearly the same temperature as the normal Snoek effect and has very close values of activation energy and relaxation time to the values of the normal Snoek effect. This feature is regarded as the main property of the DESE in metals /7/. The DESE in bcc and fcc metals has been recently reviewed by Magalas /7/. The origin of the DESE lies in the elastic interaction between moving dislocations and point defects which possess lower symmetry than the lattice and have some mobility in the lattice at the temperature of the DESE. Since the DESE has been differently named by many authors (like the α₂ peak in Ta -0 /9,10/, the β₂ peak in Fe /8,11/ as well as induced Snoek peak, enhanced Snoek peak effect, the influence of dislocations on the Snoek peak, dislocation enhanced induced Snoek peak etc), it is suggested to eliminate this gamut of names by using the following name " the dislocation-enhanced Snoek effect-DESE " as introduced in /7/; or when describing an internal friction peak to use the name " the dislocation-enhanced Snoek peak-DESP " /5/.

II - EXPERIMENTAL METHODS

The samples of 1 mm diameter and 100 mm in length were prepared from high purity CEN.G iron /8,11/ doped with 40 ppm of nitrogen /5,7/ and are referred to as Fe-N/40/. The carbon concentration in Fe-N/40/ iron after saturation from 823 K was lower than 5 ppm /6/. The samples of technical purity Armaco iron were annealed in hydrogen atmosphere at 823 K for 2,3,4, and 5 hrs and cooled down with the furnace. The internal friction /IF/ was measured in inverted torsion pendulum operating with a maximum shear strain amplitude of 1.9x10⁻⁵ and with controled heating or cooling rate of 200 Kh⁻¹. After torsional cold work /CW/ inside the pendulum the samples were immediately cooled down to 77 K within 15 sec.

III - EXPERIMENTAL RESULTS

The transformation of nitrogen Snoek effect /curve O/ into the
nitrogen DESE/N/ in Fe-N/40/ is shown in Fig.1 after 6% CW at room temperature /RT/ /curve 1/ and 13% CW at RT /curve 2/. The height of the DESE/N/ is proportional to the amount of CW at RT. The same relationship had already been found for carbon DESE/C/ in iron /5/. Fig.2 illustrates thermal instability of the DESE/N/ generated by 12% CW at RT. IF and modulus "loops" are created in subsequent runs on warm-up from 100 K to 280 K and cool-down followed by new runs up to higher temperatures. Simultaneously the shear modulus measured at 100 K was increased in each new run. This effect can be accounted for in terms of successive dislocation pinning by nitrogen atoms which was recently discussed in /7/.

The DESE/C/ in iron doped with 25 ppm of carbon is 30% higher than in iron doped with 1000 ppm of C after the same CW /7/. Sugeno /13/ observed a similar effect in nitrogen doped iron which was reviewed in /7/. As shown in Fig.3 the DESE in Armco iron after 10% CW at RT is higher for longer annealing time in hydrogen atmosphere. This experiment was repeated a few times and each time for lower FIA concentrations a higher DESE was detected. It can be concluded, therefore, that the DESE is stronger for lower concentration of FIA's in iron.

The nitrogen DESE/N/ can also be observed in Fe-N alloys after a redformation at RT of an already deformed and aged sample /for details see /7/. This refers both to Fe-C and Fe-N alloys and confirms the suggestion that fresh dislocations are involved in the DESE /5/.

It should be mentioned that the $\beta$ peak in high purity CEN.G iron /C<5 ppm/ which occurs around 330 K /8,11/ is, in fact, the DESE/C/ /7/.

**IV - DISCUSSION**

The activation parameters of the DESE in bcc metals are collected in Table I which indicates that the activation parameters of the DESE and the normal Snoek effect are nearly the same. The general properties of the DESE in bcc metals can be explained by the following models.

1. The first model is very close to the original idea of Schoeck /14/. The DESE is caused by a movement of non-screw /7/ dislocations /which possess small Peierls barrier/ in a cloud of FIA's. For an appropriate frequency of dislocation vibration a drag force occurs. The drag force results from the fact that an area in which a redistribution of elastic dipoles took place lags behind moving dislocations. Since the drag force is proportional to the relaxation time of Snoek effect the DESE should have similar activation parameters to the Snoek effect /see Table I/.

2. In the second model the mode of dislocation movement is described in terms of kink pair formation on non-screw dislocations /16/. This model is only valid if long range migration of FIA's is neglected and \( \phi_{eq} / \phi_{eq} \) is the equilibrium concentration of the kinks, L is the distance between obstacles along dislocation/. In addition, if we consider non-linear behaviour of drag force versus kink velocity and if we represent the kink viscosity in terms of viscous drag coefficient /3/ the activation energy of such a process is given by:

\[
H = H_k + H^S + \frac{kT}{2} \ln \left( \frac{0.03 + 0.8 + 0.013}{eV} \right) = 0.843 \text{ eV},
\]

which is in excellent agreement with the experiment on the carbon DESE in iron /5/, see Table I. A similar agreement can be easily found for Ta-0.

3. The third model was proposed by Ogurtani and Seeger /3,4/. They calculated the IF effect due to the motion of FIA's in the presence of a harmonically oscillating /with small amplitude/ elementary rigid kink along the dislocation line of screw and non-screw orientation on \{110\} plane. According to Ogurtani /4/ the relaxation strength of the
DESE is

$$\Delta_{\text{DESE}} = \alpha \frac{k_B^4 c_0 \lambda^2}{N_k}$$

where $C_0$ is the mean concentration of FIAs in the sample before a rearrangement of FIAs in the stress field took place, $N_k$ is the density of kinks, $\lambda$ is the principal value of the elastic dipole tensor, and $\alpha$ is a constant. The relaxation strength for screw and non-screw dislocations is roughly the same /4/. According to this model the DESE should resemble an ideal Debye peak with only possible small broadening at the high temperature side. Although a direct experimental verification of the Ogurtani model /4/ is not possible, this model can be at least partially verified in tungsten which is considered as an isotropic bcc metal.

The model of Ogurtani and Seeger does not agree with the experimental results of higher DESE for lower FIAs concentration /Fig.3/ and can not explain the broadening of the DESP in doped iron /the broadening parameter $\beta = 2\pm3.5$/ . In fact, only in pure Fe /C<5 ppm/ and in pure Ta /O<3 ppm/ the DESP resembles an ideal Debye peak.

As mentioned above the DESE is a metastable effect in iron while in Ta and Nb it is fairly stable against annealing treatment. Different annealing behaviour can be, however, explained in terms of different binding energies of point defects and dislocations /7,16/, which results in different stability of the corresponding Snoek atmospheres in Fe-C,Fe-N and Ta-O,Nb-O alloys.

Further investigation on the temperature dependence of the relaxation strength and $\beta$ parameter should provide an argument in favour of the 1st and 3rd or the 2nd model. Nevertheless, it can be pointed out that non-screw fresh dislocation segments are mainly responsible for the DESE. Although no experimental results are available so far to reveal one of the above mentioned modes of dislocation movement hampered by point defects and to define the relaxation mechanism of the DESE it seems that the 1st model offers a reasonable explanation of the DESE.

ACKNOWLEDGEMENT

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REFERENCES

Fig. 1 - The DESE/N/ in Fe-N/40/ after 6% CW at RT and 13% CW at RT, curves 1, 2, respectively. The initial Snoek peak is indicated by curve 0.

<table>
<thead>
<tr>
<th>Alloy</th>
<th>IF peak</th>
<th>$H^c$ (eV)</th>
<th>$T_{max}$ [K]</th>
<th>$\tau_0$ [s]</th>
<th>Literature</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fe-C</td>
<td>Snoek</td>
<td>0.835</td>
<td>308</td>
<td>$5.5 \times 10^{-15}$</td>
<td>Nowick [1]</td>
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<tr>
<td></td>
<td>DESE/C</td>
<td>0.84±0.03</td>
<td>313</td>
<td>$10^{-12} \pm 10^{-13}$</td>
<td>Diehl [12]</td>
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<td></td>
<td>1000ppm</td>
<td>0.85</td>
<td>~330</td>
<td>—</td>
<td>Magalas [7]</td>
</tr>
<tr>
<td>Fe-N</td>
<td>Snoek</td>
<td>0.796</td>
<td>290</td>
<td>$5.3 \times 10^{-15}$</td>
<td>Nowick [1]</td>
</tr>
<tr>
<td></td>
<td>DESE/N/</td>
<td>0.79</td>
<td>2999</td>
<td>$5.7 \times 10^{-15}$</td>
<td>Weller [15]</td>
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<tr>
<td>Fe-O</td>
<td>Snoek</td>
<td>0.76±0.004</td>
<td>419.7</td>
<td>$8.56 \pm 2.5 \times 10^{-15}$</td>
<td>Weller [17]</td>
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<tr>
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<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Ta-O</td>
<td>Snoek</td>
<td>112±0.04</td>
<td>420</td>
<td>$7.95 \times 10^{-15}$</td>
<td>Rodrigo [9,10]</td>
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<tr>
<td></td>
<td>DESE/O/</td>
<td>117±0.04</td>
<td>~420</td>
<td>$2.65 \times 10^{-15}$</td>
<td>Rodrigo [9,10]</td>
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<tr>
<td>Nb-O</td>
<td>Snoek</td>
<td>115±0.01</td>
<td>422.1</td>
<td>$2.65 \pm 0.8 \times 10^{-15}$</td>
<td>Weller [17]</td>
</tr>
<tr>
<td></td>
<td>DESE/O/</td>
<td>—</td>
<td>~422</td>
<td>—</td>
<td>—</td>
</tr>
</tbody>
</table>

Table I: The activation parameters of the DESE and the Snoek effect in bcc alloys.

Fig. 2 - The instability of the DESE/N/ in Fe-N/40/ after 12% CW at RT shown in successive IF runs from 100 K to the following temperatures: 280 K, 300 K, 310 K, 320 K, 330 K, 340 K, 360 K, 380 K, curves 1, 2, 3, 4, 5, 6, 7, 8, respectively. The changes of the shear modulus are shown in the upper part of the figure.

Fig. 3 - The DESE in Armco iron annealed at hydrogen atmosphere at 823 K for 0, 2, 3, 4, 5 hrs and deformed 10% at RT, curves 0, 2, 3, 4, 5, respectively.