Anomalous magneto-elastic coupling in Au-doped BaFe$_2$As$_2$

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We used polarization-resolved Raman scattering to study magneto-elastic coupling in Ba(Fe$_{1-x}$Au$_x$)$_2$As$_2$ crystals as a function of light Au-doping, materials for which temperatures of the structural transition ($T_S$) and of the magnetic ordering transition ($T_N$) split. We study the appearance of the $A_g$(As) phonon intensity in the $XY$ scattering geometry that is very weak just below $T_S$, but for which the intensity is significantly enhanced below $T_N$. In addition, the $A_g$(As) phonon shows an asymmetric line shape below $T_N$ and an anomalous linewidth broadening upon Au-doping in the magnetic phase. We demonstrate that the anomalous behavior of the $A_g$(As) phonon mode in the $XY$ scattering geometry can be consistently described by a Fano model involving the $A_g$(As) phonon mode interacting with the $B_{2g}$ symmetry-like magnetic continuum in which the magneto-elastic coupling constant is proportional to the magnetic order parameter.

I. INTRODUCTION

It is widely accepted that the magnetic and electronic properties of the Fe-based superconductors are very sensitive to the Fe-As-Fe bond angle of the Fe-As tetrahedra [1–13]. The $c$-axis vibration of the As atom corresponds to a fully symmetric phonon mode ($A_{1g}$) that modulates these two parameters. First-principles calculations show that the phonon mode frequencies agree well with experiments when the Fe magnetic ordering is included [14–20], and theoretical investigations suggest that the electron-phonon coupling constant is enhanced in the magnetic state [16, 21–24]. The peak position of the fully symmetric As phonon density-of-states in the calculation with an anomalous linewidth broadening upon Au-doping in the magnetic phase. We demonstrate that the anomalous behavior of the $A_g$(As) phonon mode in the $XY$ scattering geometry can be consistently described by a Fano model involving the $A_g$(As) phonon mode interacting with the $B_{2g}$ symmetry-like magnetic continuum in which the magneto-elastic coupling constant is proportional to the magnetic order parameter.

coupling. In agreement with previous Raman studies on Ba(Fe$_{1-x}$Co$_x$)$_2$As$_2$ [28, 29], we also observed an asymmetric line-shape for the fully symmetric As mode below $T_N$ in the same $XY$ scattering geometry. Our results are described by a Fano model involving a coupling between the fully symmetric As mode and the $B_{2g}$ electronic continuum, with the coupling constant proportional to the magnetic order parameter [32]. The purpose of this paper is to detail this model and to apply it to Au-doped BaFe$_2$As$_2$, a system where the structural phase transition temperature $T_S$ is a few Kelvin degrees higher than the magnetic phase transition temperature $T_N$ [33, 34]. The experimental results support the previous observations, confirm the validity of the model, and gives about 1.5 meV as an estimate of the magneto-elastic coupling constant in the parent compound. Interestingly, we find

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an anomalous linewidth broadening upon Au-doping, essentially limited to the magnetic phase.

II. EXPERIMENT AND METHODS

Single crystals of Ba(Fe$_{1-x}$Au$_x$)$_2$As$_2$ ($x = 0$, 0.012, 0.014 and 0.031) were grown out of self-flux using a high-temperature solution-growth technique described in Refs. [33, 35], and the chemical compositions were determined by inductive coupled plasma analysis [33]. Neutron diffraction measurements on Au-doped samples were performed using the four-circle diffractometer HB-3A at the High Flux Isotope Reactor (HFIR) at the Oak Ridge National Laboratory to distinguish the structural and magnetic transitions. A neutron wavelength of 1.542 Å was used from a bent perfect Si-220 monochromator [36]. The corresponding structural phase transition temperatures ($T_S$) for Ba(Fe$_{1-x}$Au$_x$)$_2$As$_2$ are determined by the temperature evolution of the integrated intensity of lattice Bragg peak (2 2 0) in the tetragonal phase to (4 0 0) in the orthorhombic phase [Fig. 2]. The corresponding magnetic phase transition temperature ($T_N$) is determined for each sample composition from the temperature evolution of the magnetic Bragg peak intensities ($\frac{1}{2}$ $\frac{1}{2}$ 5) in the tetragonal phase to (1 0 5) in the orthorhombic phase [Fig. 2]. The $T_S$ and $T_N$ for the parent compound BaFe$_2$As$_2$ are determined by resistivity and magnetic susceptibility measurements [33]. All the $T_S$ and $T_N$ values for Ba(Fe$_{1-x}$Au$_x$)$_2$As$_2$ are summarized in Table 1.

The crystals used for Raman scattering were cleaved and positioned in a continuous helium flow optical cryostat. The Raman measurements were performed using the Kr$^+$ laser line at 647.1 nm (1.92 eV) in a quasi-back scattering geometry along the crystallographic c-axis. The excitation laser beam was focused into a 50×100 µm$^2$ spot on the ab-surface, with the incident power around 10 mW. The scattered light was collected and analyzed by a triple-stage Raman spectrometer, and recorded using a liquid nitrogen-cooled charge-coupled detector.

The laser heating in the Raman experiments is determined by imaging the appearance of stripes due to twin domain formation at the structural phase transition temperature $T_S$ [29]. When stripes appear under laser illumination, the spot temperature is just slightly below $T_S$, thus $T_S = kP + T_{cryo}$, where $T_{cryo}$ is the temperature of cold helium gas in the cryostat, $P$ is the laser power and $k$ is the heating coefficient. By recording $T_{cryo}$ when the stripes appear at different laser powers, we can deduce the heating coefficient using a linear fit: $k = 1 ± 0.1$ K/mW.

In this manuscript, we define the X and Y directions along the two-Fe unit cell basis vectors (at 45° degrees from the Fe-Fe directions) in the tetragonal phase, whereas $X'$ and $Y'$ are along the Fe-Fe directions [Fig.1].

III. RESULTS AND DISCUSSIONS

The body-centered crystal structure of BaFe$_2$As$_2$ in the high temperature phase belongs to space group $I4/mmm$ (point group $D_{4h}$). Below $T_S$, the space group symmetry lowers to $Fmma$ (point group $D_{2h}$). The

![FIG. 2. Neutron diffraction results for Ba(Fe$_{1-x}$Au$_x$)$_2$As$_2$.](image-url)

TABLE I. Summary of the structural and magnetic phase transition temperatures (Kelvin) for samples studied in this manuscript. The last column is the ordered moment ($\mu_B$) per Fe at 4 K determined by neutron scattering measurements.

| Sample                     | $T_S$ | $T_N$ | $M$   |
|----------------------------|-------|-------|-------|
| BaFe$_2$As$_2$             | 135   | 135   | 0.87  [37] |
| Ba(Fe$_{0.88}$Au$_{0.012}$)$_2$As$_2$ | 108   | 100   | 0.50±0.02 |
| Ba(Fe$_{0.86}$Au$_{0.014}$)$_2$As$_2$ | 96    | 92    | 0.42±0.04 |
| Ba(Fe$_{0.96}$Au$_{0.031}$)$_2$As$_2$ | 63    | 54    | 0.36±0.02 |
non-degenerate Raman active phonon modes at high-temperature ($D_{4h}$) are $A_{1g}(As)+B_{1g}(Fe)$. The Raman selection rules for the $D_{4h}$ point group indicate that the $XX$, $XY$, $X'X'$ and $X'Y'$ scattering geometries probe $A_{1g}+B_{1g}$, $A_{2g}+B_{2g}$, $A_{1g}+B_{2g}$ and $A_{2g}+B_{1g}$, respectively. However, in the orthorhombic phase with $D_{2h}$ point group symmetry, the unit cell of BaFe$_2$As$_2$ rotates by 45 degrees; the $A_{1g}$ and $B_{2g}$ representations of the $D_{4h}$ point group merge into the $A_g$ representation of the $D_{2h}$ point group, and $A_{2g}$ and $B_{1g}$ ($D_{4h}$) merge into $B_{1g}$ ($D_{2h}$).

In the orthorhombic phase, the three proper scattering polarization geometries are $X'X'$, $Y'Y'$ and $XY'$. Since the orthorhombicity is small, the improper $XX$ and $XY$ polarizations still probe $A_g+B_{1g}$ and $A_g$ symmetry excitations, respectively. The symmetry correspondence for the point groups $D_{4h}$ and $D_{2h}$ are summarized in Table II [39].

In Figs. 3(a)-3(d), we show detailed temperature evolution of Raman spectra for Ba(Fe$_{1-x}$Au$_x$)$_2$As$_2$ ($x = 0$, 0.012, 0.014 and 0.031) in the $XY$ scattering geometry. The $T_S$ and $T_N$ values of each sample, carefully characterized by neutron scattering [Fig. 2], are indicated in each panel. For the parent compound BaFe$_2$As$_2$ [Fig. 3(a)], the $A_g(As)$ phonon mode appears instantaneously below 134 K, which is close to $T_S$ and $T_N$. The phonon mode rapidly sharpens upon cooling and becomes more symmetric. For Ba(Fe$_{0.988}$Au$_{0.012}$)$_2$As$_2$, $T_S$ (108 K) and $T_N$ (100 K) are split. The Raman data, displayed in Fig. 3(b), show that the $A_g(As)$ mode is hardly detectable between $T_S$ and $T_N$. Similarly as in Co-doped BaFe$_2$As$_2$, the mode gains strength only below $T_N$ [40]. Although the asymmetry of the phonon line shape decreases upon cooling, we note that it remains more asymmetric than in pristine BaFe$_2$As$_2$ down to the lowest temperature. We report similar observation for Ba(Fe$_{0.986}$Au$_{0.014}$)$_2$As$_2$ [Fig. 3(c)] and

![Graphical representation of Raman spectra](image)

**TABLE II.** Summary of symmetry analysis in the $D_{4h}$ and $D_{2h}$ point groups [38].

| Geometry | $D_{4h}$       | $D_{2h}$       |
|----------|----------------|----------------|
| $XX$     | $A_{1g}+B_{1g}$| $A_g+B_{1g}$   |
| $XY$     | $A_{2g}+B_{2g}$| not a proper geometry | $A_g+B_{1g}$   |
| $X'X'$   | $A_{1g}+B_{2g}$| $A_g$          |
| $X'Y'$   | $A_{2g}+B_{1g}$| $B_{1g}$       |
| $ZZ$     | $A_{1g}$       | $A_g$          |
Ba(Fe_{0.969}Au_{0.031})_2As_2 [Fig. 3(d)] [41], although the peak becomes broader due to the disorder introduced by Au-doping.

Broadening of the spectra due to the disorder introduced from dopants is expected. However, Fig. 4 indicates that the disorder effect in Ba(Fe_{1-x}Au_x)_2As_2 is far from trivial. Indeed, the data show a broader line-width at 20 K than at 300 K. This would be expected only if disorder itself has a strong impact on the magneto-elastic coupling. In Figs. 4(a) and 4(b), we compare the doping evolution of the \( A_{1g} / A_g(\text{As}) \) phonon in the \( X'X' \) scattering geometry at 300 K and 20 K. At 300 K, in the non-magnetic phase, the \( A_{1g}(\text{As}) \) phonon is symmetric and shows nearly doping-independent mode frequency, linewidth and intensity, as shown in Fig. 4(a). Fig. 4(b) illustrates contrasting behavior for the \( A_g(\text{As}) \) phonon at 20 K. We observe significant broadening, weakening, softening and a pronounced asymmetric line-shape upon Au-doping. Similar anomalous \( A_g(\text{As}) \) phonon behavior in the magnetic phase is also detected in the \( XY \) scattering geometry at 20 K [Fig. 4(c)].

Before moving forward with a more quantitative analysis of the \( A_g(\text{As}) \) phonon, it is instructive to take a closer look at the \( B_{1g} \) phonon, associated with the vibration of the Fe atom along the \( c \) axis. While below the orthorhombic transition, the \( A_{1g} \) phonon is symmetry-allowed to couple to the \( B_{2g} \)-like electronic continuum, such coupling is not possible for the \( B_{1g}(\text{Fe}) \) phonon, and accordingly, the line shape of this mode in the \( X'Y' \) configuration remains symmetric for all temperatures. However, \textit{a priori} the \( B_{1g}(\text{Fe}) \) phonon could couple to the \( B_{1g} \)-like electronic continuum. To investigate this possibility, we display in Fig. 5 the temperature evolution of the \( B_{1g}(\text{Fe}) \) phonon at different Au-doping levels.

Upon cooling, the \( B_{1g}(\text{Fe}) \) phonon mode hardens and sharpens without detected anomalies around \( T_S/T_N \) (see Figs. 6(a)-6(d)), except for the linewidth of the parent compound BaFe\(_2\)As\(_2\), which displays a discontinuity around \( T_S/T_N \) [42]. The temperature dependence of the mode frequency and linewidth for the four Au-doping concentrations can be fitted by the anharmonic phonons decay model [43, 44]:

\[
\omega_{ph}(T) = \omega_0 - C \left( 1 + \frac{2}{\hbar \omega_0 e^\frac{2\Gamma}{\hbar \omega_0} - 1} \right) \tag{1}
\]

\[
\Gamma_{ph}(T) = \Gamma_0 + \Gamma \left( 1 + \frac{2}{\hbar \omega_0 e^\frac{2\Gamma}{\hbar \omega_0} - 1} \right). \tag{2}
\]

The fitting parameters are summarized in Table III. The \( B_{1g}(\text{Fe}) \) phonon shows slight softening and broadening upon Au doping. There is no indication of a coupling between the \( B_{1g}(\text{Fe}) \) phonon and the \( B_{1g} \) electronic continuum. We also note that the linewidth of the \( B_{1g}(\text{Fe}) \) phonon broadens only by 1 cm\(^{-1}\) from \( x = 0 \) to \( x = 0.031 \) at 20 K, demonstrating that Au-doping barely affects the \( B_{1g}(\text{Fe}) \) phonon, in contrast to the \( A_g(\text{As}) \) phonon.

As discussed in Ref. [32], the enhancement of the \( A_g(\text{As}) \) phonon intensity upon entering the magnetic

![FIG. 4](image_url) (a) Doping dependence of the \( A_{1g}(\text{As}) \) phonon peak in Ba(Fe\(_{1-x}\)Au\(_x\))\(_2\)As\(_2\) in the \( X'X' \) scattering geometry at 300 K. (b) Same as (a) but at 20 K. (c) Same as (b) but in the \( XY \) scattering geometry.

![FIG. 5](image_url) (a) \( x = 0 \), (b) \( x = 0.012 \), (c) \( x = 0.014 \), (d) \( x = 0.031 \). The solid line are the Lorentzian fits of the \( B_{1g}(\text{Fe}) \) phonon peak at different temperatures.

| Sample                  | \( \omega_0 \) | \( C \) | \( \Gamma_0 \) | \( (\text{cm}^{-1}) \) |
|-------------------------|---------------|-------|--------------|-----------------|
| BaFe\(_2\)As\(_2\)     | 217.25        | 1.97  | -            | -               |
| Ba(Fe\(_{0.988}\)Au\(_{0.012}\))\(_2\)As\(_2\) | 216.54        | 2.02  | 2.14         | 0.67            |
| Ba(Fe\(_{0.986}\)Au\(_{0.014}\))\(_2\)As\(_2\) | 216.28        | 1.92  | 2.22         | 0.68            |
| Ba(Fe\(_{0.969}\)Au\(_{0.031}\))\(_2\)As\(_2\) | 215.14        | 1.89  | 2.46         | 0.61            |
phase is related to the magnetic moment. Although there is increasing evidence for a description of the magnetism of the Fe-based superconductors beyond simple weak coupling or strong coupling theories [45], it is worth looking at these theories in order to get hints on a microscopic description of the enhancement of the $A_g$ (As) phonon intensity.

The enhancement of the $A_g$ (As) phonon intensity can be rationalized in several ways. A previous theoretical paper [23] proposes two mechanisms to explain the enhancement of the $A_g$ (As) phonon intensity due to the electron-phonon coupling upon entering the magnetic phase. The first mechanism is directly related to the geometrical parameters such as the Fe-As-Fe angle, whereas the second one has to do with the modification of the Fe-As Slater-Koster energy integrals $pds$ and $pd\pi$ due to As displacements. Both mechanisms result in finite intensity in the $B_{2g}$ channel when the magnetic moment is finite, which is consistent with our experimental results.

The $A_g$ (As) phonon intensity enhancement can also be understood from a $J_1 - J_2$ model derived from the strong coupling approach [46–48]. Here the effective nearest and next-nearest neighbors super-exchange parameters $J_1$ and $J_2$ are determined by the details of the Fe-As-Fe configuration. Below $T_N$, the effective super-exchange constant $J_1$ becomes anisotropic along the $X$' and $Y$' directions, either due to the anisotropy of the ordered magnetic moment [49], or due to the difference in the electron hopping probability along and perpendicular to the stripe directions [50]. As the $A_g$ (As) phonon $c$-axes vibration modulates the effective super-exchange parameters $J_{1a}$ and $J_{1b}$ via the As bridge, $|J_{1a} - J_{1b}|$ is also modulated because the super-exchange Fe-As-Fe path along the $X'$ and $Y'$ directions are different. The relative anisotropy of the in-plane electronic polarizability along the $X'$ and $Y'$ directions, as induced by the $A_g$ (As) phonon, is proportional to $|J_{1a} - J_{1b}|$. The $|J_{1a} - J_{1b}|$ term becomes nonzero only below $T_N$ when the collinear AFM order is established, explaining why the $A_g$ (As) phonon in the $XY$ geometry appears below $T_N$ with enhanced intensity.

Whether it originates from the local mechanism described just above, or it is caused by the bi-quadratic interaction revealed to be large due to deviations from a local picture [51], the effective $|J_{1a} - J_{1b}|$ term, proportional to the in-plane electronic polarizability, was shown to be proportional to the square of the magnetic ordered moment $M$ [49]. Furthermore, the $A_g$ (As) phonon intensity ratio in $XY$ and $XX$ scattering geometries $I_{XY}/I_{XX}$ is also demonstrated to scale with the square of the magnetic ordered moment $M$ [32]. These results suggest a magneto-elastic coupling with a strength proportional to the magnetic order parameter [25, 52, 53], a fact that we are going to exploit.

In order to quantify the electron-phonon interaction evidenced by the Raman data in the $XY$ scattering geometry below $T_N$, we introduce a Fano model in which the $A_g$ (As) phonon couples to the $B_{2g}$-like electronic continuum [32]. The resulting line shape, which describes the interference between a discrete phonon mode and an interacting continuum [54–56], has the following form:

$$I(\omega) = \frac{T^2}{e} \pi \rho (\omega_0 - \omega - \nu \frac{T_N}{T})^2 \left( \omega_0 - \omega \right)^2 + (v^2 \pi \rho)^2$$

(3)

where $\omega_0$ is the bare phonon frequency, $\nu$ is the magneto-elastic coupling constant, $T_{ph}$ and $T_e$ are the Raman coupling amplitudes to the phonon and to the electronic continuum, respectively, and $\rho$ is the electronic density-of-states in the vicinity of the phonon frequency.

For BaFe$_2$As$_2$, we derive the temperature dependence of the magnetic order parameter $M(T) = b(1 - T/135)^{0.103}$ obtained from the fitting of the temperature evolution of the $(1 0 3)$ magnetic Bragg peak intensity [57] (the magnetic Bragg peak intensity is proportional to the square of the magnetic order parameter). Since $\omega_0$ barely changes upon cooling, we use the constant $\omega_0 = 181.4$ cm$^{-1}$ derived from the peak frequency in the $XX$ scattering geometry at 15 K. We also fix the coupling of light to the electronic continuum $T_e^2 = 1.4$, and we keep $T_{ph}/T_e$ and $\rho$ as two $T$-dependent fitting parameters. The spectrum at 15 K is well reproduced with $T_{ph}/T_e = 0.9$, $\rho = 0.006$ states/cm$^{-1}$, and $v = 11$ cm$^{-1}$. The temperature dependence of $v(T)$, which is proportional to the magnetic order parameter, is shown in Fig. 7(a).

The temperature evolutions of $T_{ph}/T_e(T)$ and $\rho(T)$ are illustrated in Figs. 7(b) and 7(c), respectively.

For Au-doped BaFe$_2$As$_2$ below $T_N$, we convolute the Fano intensity $I(\omega)$ with a Gaussian inhomogeneous broadening factor $\sigma(x)$. The $\sigma(x)$ broadening is determined by fitting the spectra at the lowest temperature figures...
for each doping. The $\sigma(x)$ values are summarized in Fig. 7(d).

The temperature dependence of the (105) Bragg peak intensity below $T_N$ is fitted with the formula $I(T) = a[1 − (T/T_N)^\alpha]^3$ [23], as shown in Fig. 2. Thus, the normalized magnetic order parameter $M(T)$ is obtained using $M(T) = c[1 − (T/T_N)^\alpha]^2$ [Table IV]. As shown in Figs. 3(b)-3(d), the Raman data for the Au-doped samples are well described by the model. The corresponding temperature dependence of $T_{ph}/T_e(T)$ and $\rho(T)$ for all Au dopings are given in Figs. 7(b) and 7(c), respectively. The sets of fixed parameters are given in Table IV. We note that we have normalized the parameters $v$ and $\frac{1}{\omega_0}$ to their values at 20 K. We also kept the electronic continuum transition matrix element $T_e$ the same for all Au-doping concentrations.

As shown in Fig. 7(b), the Raman coupling amplitude to the phonon $(T_{ph})$ increases upon cooling as an order parameter. This observation is reasonable because $T_{ph}$ itself should be proportional to the lattice orthorhombicity $\delta$.

The electronic density-of-states represented by the parameter $\rho(T)$ decreases upon cooling, which is consistent with the opening of a spin-density-wave gap [28, 39, 58, 59]. This observation provides a natural explanation for the reduction of the asymmetry in the $A_g(\text{As})$ phonon line shape upon cooling below $T_N$ [28].

The parameter $\sigma(x)$ describes the inhomogeneous broadening effect due to the Au substitution of Fe. As shown in Fig. 1(c), the non-magnetic Au disorder introduced at the Fe position significantly perturbs the local magnetic order and weakens the Fe-Fe spin-spin correlation length. Indeed, only 3.1% Au-doping is sufficient to lower $T_N$ from 135 K to 53 K. Each non-magnetic local Au dopant has four As neighbors and effectively changes the coupling strength between the $A_{1g}(\text{As})$ mode and the local Fe magnetic order parameter. The Au-doping has a major effect on the $A_g(\text{As})$ phonon, unlike the $B_{1g}(\text{Fe})$ phonon. The broadening of the $A_g(\text{As})$ phonon at $x = 0.031$ is 9 cm$^{-1}$, while it is only 1 cm$^{-1}$ at 20 K for the $B_{1g}(\text{Fe})$ phonon. The significant broadening of the $A_g(\text{As})$ phonon mode upon Au-doping in the magnetic state indicates a strong coupling of the $A_g(\text{As})$ phonon to magnetism [23].

Finally, the enhanced electron-phonon coupling in the collinear AFM phase may have implications to superconductivity in the Fe-based superconductors. Earlier calculations of the electron-phonon coupling constant $\lambda$ in the nonmagnetic phase led to $\lambda = 0.2$ [60]. According to recent calculations, the electron-phonon matrix element is enhanced four times in the collinear AFM phase due to the presence of $d_{xz}/d_{yz}$ Fermi surfaces around the $M$ point [24, 61]. The enhancement is notably important at 22 meV in the Eliashberg $\alpha^2F$ spectral function, which coincides with the energy of the $A_{1g}$ mode. Therefore,

![Table IV. Summary of fixed parameters.](image)

![Figure 7.](image)
the intra-band paring temperature is possibly enhanced due to the electron-phonon coupling.

IV. CONCLUSION

In conclusion, we used polarized Raman scattering to study Au-doped BaFe$_2$As$_2$ samples for which the $T_S$ and $T_N$ transition temperatures split. Our results confirm that the intensity of the $A_g$(As) mode in the XY scattering geometry is enhanced only below $T_N$ and also reveal an asymmetric phonon line shape of the $A_g$(As) mode that becomes more symmetric upon cooling. To describe the line shape of the phonon peaks, we adopted a Fano model accounting for the magneto-elastic coupling. The enhancement of intensity below $T_N$ is consistent with a magneto-elastic coupling constant proportional to the magnetic order parameter, allowing to transfer the apparent phononic Raman intensity from the electronic continuum [62]. The magneto-elastic coupling constant, estimated to about 1.5 meV in the parent compound, is non-negligible. The temperature dependence of the line shape asymmetry is explained by the interference of the coherent light scattering amplitudes due to the As phonon mode and the interacting XY-symmetry continuum, the intensity of which monotonically diminishes upon cooling as the spin-density-wave gap opens when the magnetic order develops.

We also note that when the magnetic Fe atom is substituted by non-magnetic Au at a few per cent level, the $B_{1g}$(Fe) phonon associated with the Fe c-axis vibration shows only little disorder-induced broadening. In contrast, the anomalous $A_g$ symmetry As mode appearing in the XY scattering geometry below $T_N$ shows significant enhancement of the inhomogeneous broadening with Au-doping, underlying the magneto-elastic coupling mechanism. The inferred inhomogeneous broadening of the anomalous $A_g$(As) mode reaches 1 meV at 3.1% gold substitution.

The pronounced Fano line shape and significant broadening of the $A_g$(As) phonon mode upon Au-doping in the magnetic state demonstrates the strong coupling of the $A_g$(As) phonon to magnetism and to the electronic continuum in the Fe-based superconductors, with possible consequences on the intra-band paring temperature.

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