Electron dephasing near zero temperature: an experimental review

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The behavior of the electron dephasing time near zero temperature, \( \tau_\phi^0 \), has recently attracted vigorous attention. This renewed interest is primarily concerned with whether \( \tau_\phi^0 \) should reach a finite or an infinite value as \( T \to 0 \). While it is accepted that \( \tau_\phi^0 \) should diverge if there exists only electron-electron (electron-phonon) scattering, several recent measurements have found that \( \tau_\phi \) depends only very weakly on temperature, if at all, when \( T \) is sufficiently low. This article discusses the current experimental status of “the saturation problem”, and concludes that the origin(s) for this widely observed saturation are still unresolved.

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I. INTRODUCTION

The electron dephasing time, \( \tau_\phi \), is one of the most important quantities governing quantum-interference phenomena in mesoscopic structures. Recently, the behavior of the dephasing time near zero temperature, \( \tau_\phi^0 = \tau_\phi(T \to 0) \), has attracted vigorous experimental [1, 2, 3, 4, 5, 6, 7] and theoretical [8, 9, 10, 11, 12, 13] attention. One of the central themes of this renewed interest is concerned with whether \( \tau_\phi^0 \) should reach a finite or an infinite value as \( T \to 0 \). The connection of the \( \tau_\phi^0 \) behavior with fundamental condensed-matter physics problems, such as the validity of the Fermi-liquid picture [4], the possibility of the occurrence of a quantum phase transition, the persistent current problem in metals [3, 4], and also the feasibility of quantum computing, has been intensively addressed [7]. Conventionally, it is accepted that \( \tau_\phi^0 \) should reach an infinite value in the presence of only Nyquist electron-electron (e-e) and electron-phonon (e-ph) scattering. However, several recent careful measurements, performed on metal and semiconductor mesoscopic structures, have revealed that \( \tau_\phi^0 \) depends only very weakly on temperature, if at all, when \( T \) is sufficiently low. Until now, there is no generally accepted process of electron–low-energy-excitation interaction that can satisfactorily explain the widely observed saturation of \( \tau_\phi^0 \).

This article discusses existing proposals for the observed saturation of \( \tau_\phi^0 \), and surveys recent systematic efforts aimed at testing these proposals. We argue that recent measurements have extensively demonstrated electron heating, external microwave noise, and very dilute magnetic impurities cannot be the dominant source for the finite value of \( \tau_\phi^0 \) found in the experiments. We suggest that “the saturation problem” can be most unambiguously addressed using tailor-made samples covering a wide range of material properties. We also propose that three-dimensional (3D) mesoscopic structures can shed light on this issue.

II. EXTRACTING \( \tau_\phi \) FROM MAGNETO-TRANSPORT MEASUREMENTS

In quantum-interference studies, the electron dephasing time \( \tau_\phi \) is given by [18]

\[
\frac{1}{\tau_\phi(T, \ell)} = \frac{1}{\tau_\phi^0(\ell)} + \frac{1}{\tau_1(T, \ell)},
\]

where \( \ell \) is the electron elastic mean free path; \( \tau_\phi^0 \) is presumed to be independent of temperature, and \( \tau_1 \) is the relevant inelastic electron scattering time(s) in question. The temperature dependence of \( \tau_\phi \) is controlled entirely by the \( T \) dependence of \( \tau_1 \), while \( \tau_\phi^0 \) determined the value of the dephasing time in the limit of very low \( T \). In three dimensions (3D), the e-ph scattering is the sole, dominating inelastic scattering [19, 20] and \( \tau_1^{-1} \approx \tau_{ep}^{-1} \propto T^p \), with \( 2 \lesssim p \lesssim 4 \). In lower dimensions, the Nyquist e-e scattering dominates [3] and, generally, \( \tau_1^{-1} \approx \tau_{ee}^{-1} \propto T^p \) at a few kelvins and lower, with \( p = 2/3 \) in one dimension (1D) and \( p = 1 \) in two dimensions (2D).

It is well established that very reliable values of \( \tau_\phi \) in mesoscopic structures can now be extracted from magneto-transport measurements [19]. For example, Fig. 1 shows the variation of \( \tau_\phi \) with \( T \) for a thick and a thin Sb films obtained from weak-localization (WL) studies. One sees that, at the highest measurement temperatures, e-ph scattering dominates and \( \tau_\phi \) reveals a strong \( T \) dependence. In the thick film, \( \tau_\phi^{-1} \approx \tau_{ep}^{-1} \) all the way down to about 2 K; while in the thin film, e-e scattering gradually becomes more important and, thus, \( \tau_\phi^{-1} \approx \tau_{ee}^{-1} \) below about 5–6 K. In both cases, a progressively weakened \( T \) dependence is observed at the lowest measurement temperatures. We notice that (i) the overlap of the values
III. ELECTRON HEATING AND RELATED EFFECTS

Of the prominent interest on this subject is “the saturation problem”, i.e., a finite experimental value of $\tau_\phi^0$ extracted as $T \to 0$. In particular, in the WL studies, the saturation of $\tau_\phi^0$ is inferred from the low-field magnetoresistance, which does not increase as fast as expected with decreasing $T$ [4, 13]. For instance, Natelson et al. [4] found, in wide AuPd wires, that the magnetoresistance changed by less than 40% even when the temperature was significantly decreased from 4.2 down to 0.08 K. On the other hand, it should be noted that the temperature insensitive magnetoresistance at low $T$ is found in a $T$ regime where the electron gas is in thermal equilibrium with the lattice, i.e. the weak dependence is not caused by electron heating (due to either the measurement current or external noise). This assertion is clearly confirmed by the observation of a continuous resistance rise with decreasing temperature down to the lowest temperatures in each measurement [1, 3, 21]. (The resistance rise can generally be ascribed to e-e interaction effects in metal samples [13, 22].) This assertion is also confirmed in other quantum-interference studies. For example, Bird et al. [23] have extracted estimates for the dephasing length, $L_\phi = \sqrt{D\tau_\phi}$, where $D$ is the diffusion constant, in quasi-ballistic GaAs/AlGaAs quantum wires from the amplitude of the universal conductance fluctuations. They found that $L_\phi$ remained independent of $T$ below 1 K, even though the amplitude of the fluctuations themselves increased by a factor of 4 over the same range [24].

Microwave-noise dephasing. Altshuler et al. [25] have considered the electron dephasing by non-equilibrium high-frequency electromagnetic noise. They have argued that the microwave noise can already be large enough to cause dephasing, while still too small to cause significant Joule heating of the conduction electrons [3, 20]. Careful experimental measurements have recently been designed to test these predictions. These experiments [3, 23, 27] explicitly demonstrated that direct dephasing due to radiation could not be the cause of the widely observed saturation. More precisely, Webb et al. [24] and Huibers et al. [1] found that there was heating by the high-frequency noise, before it affected dephasing, i.e. electron heating preceded dephasing by high-frequency noise. Burke et al. [27] have very recently investigated the effect of externally applied broadband Nyquist noise on the intrinsic dephasing rate of electrons in 2D GaAs/AlGaAs heterojunctions at low temperatures. They also found no major change in the measured $\tau_\phi$ even when their sample was subject to large-amplitude, externally-applied, voltage fluctuations. (At the same time, heating was unimportant in their measurements.) These measurements, therefore, strongly suggests that the effect of microwave noise on electron dephasing and heating requires further theoretical clarification.
IV. MAGNETIC IMPURITIES: SPIN-SPIN SCATTERING

Over the years, the saturation behavior of $\tau_0$ has often been ascribed to a finite spin-spin scattering rate, due to the presence of a tiny amount of magnetic impurities in the sample. Such a finite scattering rate will eventually dominate over the relevant inelastic scattering in the limit of sufficiently low $T$, Eq. (1). This idea of magnetic-scattering-induced dephasing immediately became widely accepted since the discovery of WL effects two decades ago [28]. In addition to many early studies that often attributed the observed finite value of $\tau_0$ to spin-spin scattering, there are some recent studies that also argue in favor of the role of magnetic impurities. Especially, the Saclay-MSU group [3] has measured both the energy exchange rate between quasiparticles and the dephasing time of quasiparticles in several Cu, Ag, and Au narrow wires. They found in one Ag wire and one Au wire that $\tau_0$ varies as $T^{-2/3}$ down to 40 mK. (The $T^{-2/3}$ variation is expected from 1D Nyquist e-e scattering [18, 22].) Comparing these two complementary measurements, they concluded that a saturation of $\tau_0$ occurs only in wires that contain a small amount of magnetic impurities. In those wires where they found no anomalous energy exchange, they also found no sign of saturation in $\tau_0$. The Saclay-MSU group experimental results have triggered several theoretical studies [2, 24, 30] of the inference of one-channel and two-channel Kondo effects on the energy-relaxation and dephasing rates. We notice that the metal wires studied by the Saclay-MSU group are relatively “clean”, namely, their wires have a diffusion constant $D \approx 100-200 \text{ cm}^2/\text{s}$.

Proposal for non-magnetic origin. In sharp contrast to the conclusion reached by the Saclay-MSU group discussed just above, Mohanty et al. [4] have tested and argued for a non-magnetic origin for the finite value of $\tau_0$. Mohanty et al. first studied a series of very pure Au wires, finding that there was always a saturation of $\tau_0$. From these measurements, they realized that both the value of $\tau_0$ and the onset temperature of saturation could be tuned by adjusting the sample parameters such as the wire length, resistance, and diffusion constant. To explore this idea, Webb et al. [32, 33] reported further measurements on several carefully fabricated Au wires and films, whose onset temperature of saturation was indeed pushed down to unattainable temperatures ($\ll 40 \text{ mK}$). Webb et al. also noticed that a finite value of $\tau_0$ is also often observed in semiconductor mesoscopic structures. Since such structures are thought to contain only the smallest concentration of magnetic impurities, they concluded that the widely observed saturation must be universal, and cannot be simply due to magnetic scattering. (They suggested that the saturation of $\tau_0$ is intrinsic and is a signature of the breakdown of the independent single-electron picture in mesoscopic systems as $T \to 0$.)

The contradicting conclusion of the Saclay-MSU group and Webb et al. illustrates well the subtlety and complexity of “the saturation problem”. First, it is not a trivial experimental task to unambiguously determine the influence of magnetic scattering on $\tau_0$, because the level of magnetic contamination is probably so low that it cannot be readily detected with state-of-the-art material-analysis techniques. Secondly, since there are no known physical properties that are more sensitive to spin-flip scattering than the dephasing process, the problem of whether there is a tiny amount of magnetic contamination in the sample, thus, cannot be readily verified with other complimentary measurements. Moreover, the situation becomes even more serious when lower-dimensional systems are considered. In the case of low-dimensional structures, surface effects due to interfaces, substrates, and paramagnetic oxidation [22] are likely to be non-negligible. Then, it is not straightforward to ascribe the observed saturation behavior of $\tau_0$ to either intrinsic material properties or surface effects.

V. SYSTEMATIC MEASUREMENTS AND THE IMPORTANCE OF THREE-DIMENSIONAL SYSTEMS

To resolve the underlying physics of $\tau_0$, the usual experimental approach of measuring the inelastic electron processes via temperature-dependent magnetoresistance studies is not very useful. In the case of inelastic scattering, the microscopic physics of the relevant electron–low-energy-excitation interactions is extracted through the measured variation of the scattering time with $T$. However, in the case of $\tau_0$, there is only a very weak, or no, $T$ dependence involved. It is then desirable to seek variations of $\tau_0$ with the material characteristics of the samples, such as the amount of disorder [3], the sample geometry [4], the effect of annealing [33, 34], and the effect of the microscopic quality of disorder [4, 19]. Systematic information about the influence of sample properties on $\tau_0$ should shed light on the origins of the zero-$T$ dephasing mechanism.

As discussed above, an explanation for the saturation behavior of $\tau_0$ based on magnetic scattering cannot be easily discerned experimentally. This experimental difficulty results in several groups insisting on the presence of magnetic impurities in the sample as the origin of saturation. In our opinion, this problem may be resolved by studying a series of samples covering a sufficiently wide range of sample properties. For instance, Lin and Giordano [33] have performed systematic measurements of $\tau_0$ on a number of as-sputtered and annealed AuPd thin films with varying sheet resistance. They found a $\tau_0$ increasing with decreasing sheet resistance, which led them to conclude that magnetic scattering could not be the mechanism responsible. They suggested that the strength of the impurity scattering which is responsible for $\tau_0$ could be very sensitive to the metallurgical properties of the films, which are in turn a function of both thickness and annealing, etc. Since two-level sys-
tems (TLS) are closely associated with the presence of dynamical defects in the microstructures in the sample, their observation of a sensitive, metallurgical-property, influence on $\tau_0^\phi$ has recently inspired several theoretical studies of the interaction between conduction electrons and TLS [4,5].

A. Three-dimensional polycrystalline metals

Lin and Kao [3] have recently studied the electron dephasing times $\tau_0^\phi$ in numerous 3D polycrystalline disordered metals. Their samples were made of various materials, using various fabrication techniques (see the caption to Fig. 2). Since one of the major issues in this direction of research is to study whether there might exist a universal saturation behavior of $\tau_0^\phi$, the use of many kinds of samples with distinct characteristics is highly desirable. Any behavior of $\tau_0^\phi$ common to all these materials, if found, should bear important information on the nature of the zero-$T$ dephasing. Regardless of the very different preparation and measurement conditions, the authors found in numerous metals that there is a saturation of $\tau_0^\phi$ at sufficiently low $T$. Most surprisingly, they found that their experimental $\tau_0^\phi$ varied with the diffusion constant with a simple power law as

$$\tau_0^\phi \propto D^{-\alpha}, \quad \alpha \gtrsim 1$$

(2)

where $\alpha$ is close to or slightly larger than 1.

Figure 2 shows the variation of $\tau_0^\phi$ with $D$ measured by Lin and Kao. This figure indicates that the values of $\tau_0^\phi$ for all samples fall essentially on a universal dependence. Particularly, it reveals that, regardless of the distinct material characteristics (e.g., electronic structure) of the various samples, all that matters in determining the value of $\tau_0^\phi$ is $D$. (Figure 2 is a straight manifestation of this observation.) This observation of $\tau_0^\phi \propto D^{-\alpha}$, with $\alpha \gtrsim 1$, is totally unexpected. This result implies that the functional form of $\tau_0^\phi$ on disorder may be universal for a given dimensionality and a given kind of sample structure, while it may not be universal over different dimensionalities and different sample (e.g., polycrystalline, amorphous or well-textured semiconductor) structures. On the contrary, it is often conjectured that $\tau_0^\phi$ should increase with reducing disorder, at least in lower dimensions [1,2]. Until now, it is not known exactly how differently $\tau_0^\phi$ should behave in different dimensionalities and in different sample structures. This observation may also suggest that the saturation behavior of $\tau_0^\phi$ can be very different between “clean” and “dirty” metals. For comparison, the diffusion constant considered in Fig. 2 is typically 1 to 2 orders of magnitude smaller than that in the metal wires studied by the Saclay-MSU group [2] and Mohanty et al. [1,26]. On the other hand, the diffusion constant in the AuPd wires and films studied by Natelson et al. [4] is similar to that considered in Fig. 2. Consequently, Natelson et al. obtained corresponding values of $\tau_0$ very close to that shown in Fig. 2.

The result of Fig. 2 argues against the role of magnetic scattering as the dominant dephasing process in 3D polycrystalline metals as $T \rightarrow 0$. This is asserted since the numerous samples considered in Fig. 2 were made from very different high-purity sources, using very different fabrication techniques. It is hard to conceive that spin-flip scattering due to “unintentional” magnetic contamination could have caused the “systematic” variation given by Eq. (2). If magnetic scattering were responsible for the measured $\tau_0^\phi$ in Fig. 2, then the unintentional magnetic impurity concentration, $n_m$, must vary randomly from sample to sample, and hence one should expect a random $\tau_0^\phi$ ($\propto n_m^{-1}$), independent of disorder. Besides, any spin-spin scattering that might result from surface effects (substrates, paramagnetic surface oxidation, etc.) should be largely minimized in these 3D samples. Therefore, the result of Fig. 2 cannot be simply explained in terms of magnetic scattering.

The observation of Fig. 2 is still not understood. Nevertheless, this result unambiguously indicates that the saturation of $\tau_0^\phi$ in this case is certainly not due to microwave noises, because microwave-noise dephasing should result in a $\tau_0^\phi \propto D^{-1/4}$ dependence in 3D [22].

**FIG. 3:** Variation of $\tau_0^\phi$ with diffusion constant for 3D polycrystalline metals: dc sputtered Au$_{50}$Pd$_{50}$ (circles), dc/RF sputtered Pd$_{50}$Ag$_{50}$ (squares), dc sputtered Sb (triangles), thermal-flash evaporated Au$_6$Al (solid triangles), thermal-flash evaporated Sc$_{55}$Ag$_{45}$ (solid squares), and arc-melted V$_{100-x}$Al$_x$ (solid circles). The two vertical bars represent the $\tau_0^\phi$ measured in AuPd thin films in Ref. [33]. The shaded area represents the $\tau_0^\phi$ measured in AuPd wires and films in Ref. [4]. (Notice that these AuPd films and wires have short electron mean free paths and are 3D with regard to the Boltzmann transport.) The solid line is drawn proportional to $D^{-1}$ and is a guide to the eye.
B. Effect of annealing: 3D polycrystalline metals

The effect of annealing on 3D polycrystalline metals has been studied very recently. Lin et al. [34] have performed systematic measurements of $\tau_\phi$ on several series of as-sputtered and subsequently annealed AuPd and Sb thick films. Such controlled annealing measurements are crucial for testing theoretical models of dephasing that invoke the role of magnetic scattering and dynamical defects. Figure 3(a) shows a plot of the variation of $\tau_\phi$ with $T$ for one of their as-prepared and subsequently annealed AuPd thick film. This figure clearly indicates that $\tau_\phi$ is increased by annealing. At first glance, it appears that this observation is easily explained. Suppose that annealing results in the rearrangement of lattice atoms and a relaxation of grain boundaries, thereby making the film less disordered. Because TLS are closely associated with defects in the microstructures, their number concentration, $n_{TLS}$, is therefore reduced by annealing. Assuming that dynamical defects are effective scatterers as $T \to 0$, one can then understand Fig. 3(a) in terms of a TLS picture, i.e. $\tau_\phi \propto n_{TLS}^{-1}$. However, it is impossible to perform a quantitative comparison of the experiment with TLS theories [33][34]. The difficulties lie in the facts that (i) the number concentration $n_{TLS}$ in a particular sample is unknown, (ii) the strength of coupling between conduction electrons and a TLS is poorly understood, and (iii) the dynamical properties of real defects (impurities, grain boundaries, etc.) are even less clear. Moreover, further measurements of Lin et al. indicate that the nature of low-$T$ dephasing in polycrystalline metals is not so straightforward. They found that the effect of annealing on $\tau_\phi$ is distinctly different in samples having much higher resistivities.

In addition to the study of Fig. 3(a), Lin et al. [34] have also carried out measurements on AuPd thick films containing much higher levels of disorder. Surprisingly, they discovered that annealing has a negligible effect on $\tau_\phi$ in strongly disordered AuPd thick films. Figure 3(b) shows the variation of $\tau_\phi$ with temperature for a strongly disordered AuPd thick film. This figure demonstrates that the values of $\tau_\phi$ for the as-prepared and annealed samples are essentially the same, even though the resistance is changed by the annealing by a factor of more than 6. The absence of an appreciable annealing effect in this case implies that, in addition to the usual TLS addressed above, strongly disordered films also contain other defects that cannot be readily cured by annealing. This ineffectiveness of thermal annealing may suggest that there are two kinds of TLS. On the other hand, it may suggest that, despite a large effort in this direction, no real defects of any nature have dynamical properties which can explain the saturation of $\tau_\phi^0$, found in the experiments [34]. Inspection of the large discrepancy in Figs. 3(a) and 3(b) strongly indicates that low-$T$ dephasing is very sensitive to the microstructures in the samples.

We return to the issue of magnetic scattering. The result of Figs. 3(a) and 3(b) indicates that magnetic scattering should play a subdominant role, if any, in inducing the saturation of $\tau_\phi^0$. The reasons are given as follows. (i) Suppose that there is a low level of magnetic contamination in the as-sputtered film. Upon annealing, the magnetic impurity concentration $n_m$ should be left unchanged. If the original saturation in the as-sputtered sample is caused by spin-spin scattering, one should then expect the same value of $\tau_\phi^0$ ($\propto n_m^{-1}$) after annealing. However, the result of Fig. 3(a) indicates an increased $\tau_\phi^0$ with annealing, which is in disagreement with this assumption. (ii) Blachly and Giordano [36] have found that the Kondo effect is very sensitive to disorder, namely that increasing disorder suppresses the Kondo effect. Along these lines, if the original saturation of $\tau_\phi^0$ found in Fig. 3(b) were really due to magnetic scattering, one should then argue that annealing that suppresses disorder should enhance the Kondo effect. Therefore, a decreased $\tau_\phi^0$ should be expected with annealing. Since the measured $\tau_\phi^0$ does not change, even when the sample resistivity is reduced by a factor of more than 6 by annealing.
ing. Fig. 3(b) thus cannot be reconciled with a magnetic-scattering scenario. This picture of a suppressed Kondo effect with increasing disorder is also incompatible with the result for the moderately disordered film considered in Fig. 3(a), where an increased, instead of a decreased, $\tau_\phi^0$ is found after annealing. In short, systematic annealing measurements in both thin [5] and thick [3] films cannot be reconciled with magnetic scattering being responsible for the saturation of $\tau_\phi^0$ at low temperatures.

C. The importance of three-dimensional structures

It is worth noting that the saturation problem can be better addressed in 3D, rather than lower-dimensional, structures. This is because of the increased contrast between the saturation and the strong dependence of $\tau_i(T)$ in 3D. As discussed in §2, the inelastic electron scattering rate $\tau_i^{-1} \approx \tau_{ep}^{-1} \propto T^p$, with $p \gtrsim 2$ in 3D. Such a $T$ variation is much stronger than the dominating $p = 2/3$ in 1D and the $p = 1$ in 2D. For example, inspection of the solid line, which is drawn proportional to $T^{-2}$, in Fig. 3(b) clearly reveals that the measured $\tau_\phi^0$ at 0.5 K is already more than one order of magnitude lower than would be extrapolated from the measured $\tau_{ep}$ at a few degrees Kelvin. Obviously, such a large discrepancy cannot simply be ascribed to experimental uncertainty. (The increasing contrast between the saturation and the dependence of $\tau_i(T)$ with increasing sample dimensionality is already directly manifested in Fig. 3.) There is another advantage of using 3D structures in the studies of $\tau_\phi^0$. Compared with the fabrication of narrow wires, the preparation of 3D samples usually does not require sophisticated lithographic processing, thereby greatly minimizing any (magnetic) contamination that might eventually act like a spin-flipper as $T \to 0$.

VI. CONCLUSION

Over the years, the advances in our understanding of quantum-interference effects have made feasible systematic and quantitative measurements of $\tau_\phi$ ($\tau_\phi^0$). Despite extensive efforts in theoretical calculations and experimental measurements of $\tau_\phi^0$, our current understanding of the microscopic origins for the zero-$T$ dephasing in real conductors is still incomplete. Experimentally, carefully designed low-$T$ magneto-transport measurements employing tailor-made structures, with sample specifics varying over a wide range of disorder and dimensionality, would be highly desirable to help with discerning the underlying physics of $\tau_\phi^0$. In addition to the systematic studies on high-disorder 3D polycrystalline metals [5, 6], combined measurements of the electron energy exchange rate, dephasing rate, and Aharonov-Bohm oscillations in the presence of a high magnetic field will shed light on this issue [6]. Thus far, systematic measurements have ruled out electron heating, microwave noise, and magnetic scattering as the dominant source for the saturation behavior of $\tau_\phi^0$ observed in the experiments.

In addition to the case of disordered metals in the diffusive regime, a saturation of $\tau_\phi^0$ has also been observed in semiconductor, diffusive and quasi-ballistic, quantum wires, and ballistic dots [19]. In many regards, the features of this saturation appear reminiscent of that found in dirty metal wires. The saturated value of $\tau_\phi^0$ is typically of similar order in semiconductor wires and dots, and is also of comparable magnitude to that found in studies of dirty metal wires and films. The characteristic temperature for onset of the saturation also varies widely in these structures—again reminiscent of the behavior found in dirty mesoscopic systems. It is intriguing, and deserves serious investigation, why semiconductor quantum structures and dirty metals reveal similar saturation behavior of $\tau_\phi^0$.

Another important issue revealed in a number of studies is a sensitivity of the electron dephasing to the microscopic quality of disorder. For instance, Ovadyahu [1] has measured $\tau_\phi$ at low temperatures in diffusive In$_2$O$_{3-x}$ and In$_2$O$_{3-x}$:Au thin films. He found that, although the Au doping is only $\lesssim 3\%$ in In$_2$O$_{3-x}$:Au thin films, the behavior of the dephasing time in these two materials could be significantly different. Bird and co-workers [17] have studied semiconductor quantum dots and found that their $\tau_\phi$ can show significant dot-to-dot variations, in samples realized in materials with similar mobilities. These measurements reflect a critical sensitivity of the dephasing processes to disorder. These experiments clearly suggest that $\tau_\phi^0$ is not only dependent on the total level of disorder, but are also very sensitive to the microscopic quality of the disorder. This can be particularly crucial for mesoscopic devices, whose disorder profile is know to be highly sample specific. This is a key point that needs to be taken into consideration in future theories of electron dephasing times.

VII. ACKNOWLEDGEMENTS

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