I. INTRODUCTION

In the wavelength range between about 13 and 30 nm, Molybdenum/Silicon-based multilayer mirrors are the most used in applications where high normal incidence reflectivity is required. Mo/Si mirrors working as projection optics at 13.5 nm, are required by the new generation lithography systems: here, to ensure the highest throughput for high volume production, not only good in-band reflectivity is required, but also high intense EUV source. Moreover, multilayer mirrors find application as monochromators, focusing mirrors and polarimeters in synchrotron radiation facility where brighter soft x-ray beams are employed. When used with such high brilliant EUV-Soft X ray sources, multilayer coating need to ensure thermal stability as well as good in-band reflectivity. Multilayer systems consisting of pure Mo and Si are stable only up to about 100°C: as a matter of fact, Mo-Si interdiffusion and MoSi2 formation readily starts above 150°C, leading to destruction of mirror structure and performance. To improve heat stability, compound layers [1] such as molybdenum silicides and boron nitride have been used as spacer layer. Moreover, the insertion of nanometric inter-layers has proven to be effective to prevent interdiffusion of Mo and Si atoms on specific interfaces. Carbon-based [2] and silicon dioxide barrier layers [3] have been reported to enhance thermal stability in Mo/Si mirrors. Proper inter-layer materials have on one side to promote formation of stable compounds, assuring thermal and chemical stability, correct periodicity and Γ ratio (absorber thickness/period thickness); on the other side, in order to optimize EUV reflectivity, candidate materials have to present suitable optical constants. In this work, thermal stability of Mo/Si multilayer with nanometer Ruthenium inter-layer is investigated. In recent years Ruthenium has gained increasing attention as candidate material for both grazing and normal incidence EUV mirrors [4] due to the combination of optimal optical properties –it has optical constants very close to those of Mo- and chemical stability. Here we report some results of the study started in the frame of MIRRORS Project: work has been spent to optimize insertion process of thin Ru layers inside Mo/Si multilayers. In particular, Ruthenium will be considered as barrier layer at Mo-on-Si interface, which is the most critical interface in Mo/Si mirrors, and the influence of Ru thickness on performance and thermal stability of EUV mirrors will be reported.

Mo/Si-based multilayer samples have been produced by rf-magnetron sputtering at Laboratori Nazionali di Legnaro – INFN[5]. Briefly, the chamber is equipped with three planar 2” UHV type II unbalanced magnetron sputter sources and a three-position biasable sample holder. Noble gas, Ar (99.9999%), is used as process gas, at the operating pressure of 2.5·10⁻³ mbar. The base pressure of the chamber is about 5.0·10⁻⁷ mbar. The RF power (respectively 150 W for Si, 60 W for Mo e Ru) has been set in order to obtain a deposition rate of about 0.5 Å/s. A deposition run allowed production of couples of multilayers; then for every couple, one sample was subject to characterization techniques as deposited, while the other sample was subject to characterization after a thermal treatment. The samples were heated up to about 350°C for 30 min. under vacuum condition, as shown in the following graph (Fig. 1)

Fig.1. Temperature vs. time for thermally trated samples.

The samples consist of 40 periods of Mo and Si with a Ru layer at Mo-on-Si interface and a 15 Å Ru cap layer. A couple of multilayers was grown with a Ru nominal thickness of about 10 Å (say samples A), while in another one Ru barrier layer had a nominal thickness of about 5 Å (say couple B). The composition has been checked by RBS analysis, performed with an α-beam at 2.2 MeV and scattering angle of 160° at the HVEC 2.5 MeV and CN 7.0 MeV accelerator at LNL–INFN. Multilayer structural parameters are deduced from X-Ray Reflectivity measurements (XRR) performed at Dipartimento di Fisica–Università di Padova with a Philips X' Pert Pro Diffractometer: the 0-20 scans have been collected at grazing angle with Cu-Kα line. EUV reflectivity measurements have been performed at BEAR Beamline of ELETTRA Synchrotron Light Laboratory (Trieste).
III. RESULTS

Structural parameters of as-dep. samples are deduced from RBS results crosschecked with XRR measurements. As-dep multilayer of couple A and B presents respectively a period of $77.2 \pm 0.5 \text{ Å}$ and $78.5 \pm 0.5 \text{ Å}$; Ru layer thickness is respectively of about 10 Å and 4 Å (so confirming the nominal thicknesses). The absorber (Mo+Ru) phase is in both cases of about 30 Å. After thermal treatment the periodic structure of multilayer is not destroyed; as shown in Fig. 2 and 3 Bragg peaks of XRR spectra appear up to 7°. Heating leads to a period contraction due to formation of mixed phases at interfaces; investigation on this compound is still in progress. However for both couples this contraction is small: 4% for samples A and <2%, even smaller, for samples B.

Fig.2. XRR spectra of as-dep. and thermally treated samples A

Fig.3. XRR spectra of as-dep. and thermally treated samples B

Reflectivity performances before and after thermal treatments of samples A and B are shown in Fig. 4 and 5 respectively. Samples B, which have a thinner Ru inter-layers, present the best performance, reaching a maximum reflectivity up to 63% for as-dep sample; moreover, the reflectivity peak of thermally treated sample B is still 52%, so 83% of as-dep.value. In the case of couple A maximum reflectivity are 61% for as-dep sample and 45% for treated sample (73% of as-dep value).

Fig.4. EUV Reflectivity measurements of as-dep. and thermally treated samples A (normal incidence: 15° off normal)

Fig.5. EUV Reflectivity measurements of as-dep. and thermally treated samples B (normal incidence: 10° off normal)

IV. CONCLUSIONS

Insertion of thin Ru inter-layer at Mo-on-Si interface prevents thermally treated (up to 350° for 30 min.) Mo/Si multilayer reflectivity from falling down to useless values. Control of Ru thickness is important; on one hand Ru layer should be thin in order to have reflectivity performance similar to that of a ‘pure’ Mo/Si multilayer, on the other hand dose of Ru atoms should be enough to produce a barrier layer.

Work is in progress to test the influence of time of treatment on thermal stability of Ru/Mo/Si multilayers mirrors.

V. ACKNOWLEDGEMENT

Thank to D. De Salvador for support in XRR measurements.